Search for Isobaric Analogue States in ^{57}Co Via The Reaction ^{56}Fe (ρ,γ) ^{57}Co

by

Muhammad Ahmad Garwan

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

NUCLEAR PHYSICS

May, 1985

Order Number 1355748

Search for isobaric analogue states in ^{57}Co via the reaction ^{56}Fe (p,γ)^{57}Co

Garwan, Muhammad Ahmad, M.S.

King Fahd University of Petroleum and Minerals (Saudi Arabia), 1985

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

University of Petroleum and Minerals

SEARCH FOR ISOBARIC ANALOGUE STATES IN ^{57}Co VIA THE REACTION $^{56}Fe\ (p,\gamma)^{57}Co$

BY

MUHAMMAD AHMAD GARWAN

A Thesis Presented to the
FACULTY OF THE COLLEGE OF GRADUATE STUDIES

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

IN

NUCLEAR PHYSICS

MAY 1985

Printed By: UPM Printing Press

UNIVERSITY OF PETROLEUM AND MINERALS

DHAHRAN, SAUDI ARABIA

COLLEGE OF GRADUATE STUDIES

This thesis, written by MR. MUHAMMAD AHMAD GARWAN under the direction of his Thesis Committee and approved by all its members has been presented to and accepted by the Dean, College of Graduate Studies, in partial fulfilment of the requirements for the degree of Master of Science in Nuclear Physics.

Dean, College of Graduate Studies

Date : 9-3-1985

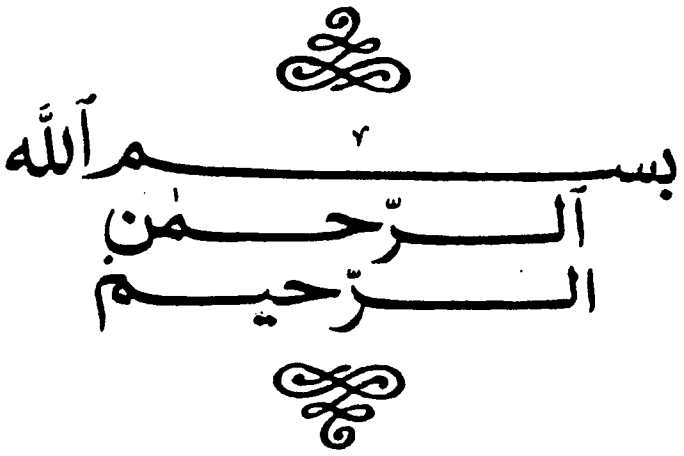
Department Chairman

Thesis Committee

Dr. M.S. El-Kateb (Chairman)

Dr. A.H. Hussein (Member)

Dr. A.K. Abdallah (Member)


بسم الله
الرحمن
الرحيم

ABSTRACT

The $^{56}Fe(P,\gamma)^{57}Co$ reaction has been studied over the proton energy range of E_p=3694-3855 keV. Four resonances were observed at E_p=3720, 3727, 3774 and 3793 keV. Decay schemes were established for the four resonances, and angular distributions were measured at E_p=3720, 3774 and 3793 keV. A $J^{\pi}=9/2^{+}$ has been assigned for the resonances at E_p=3720 and 3727 keV, and $J^{\pi}=5/2^{+}$ has been assigned for the resonances at E_p=3774 and 3793 keV.

In this work it was concluded that the two resonances at E_p=3720 and 3727 keV (E_x=9682 and 9689 keV) are fragments of an isobaric analogue state in ^{57}Co corresponding to the $g_{9/2}$ at E_x=2455 keV in ^{57}Fe. Moreover, it was concluded that the two resonances at E_p=3774 and 3793 keV (E_x=9734 and 9753 keV) are two fragments of an isobaric analogue state in ^{57}Co corresponding to the $d_{5/2}$ at E_x=2506 keV in ^{57}Fe.

Levels at E_x=4586 and 4675 keV in ^{57}Co are identified as the antianalogue states ($T^{<}$) corresponding to the $g_{9/2}$ and $d_{5/2}$ isobaric analogue states respectively.

الخلاصـــــــــــة

في هذا البحث دُرِس التفاعل النووى الناتج عن تسليط شعاع مـــــــن البروتونات بطاقة تدريجية من ٣٦٩٤ حتى ٣٨٥٥ ألف الكترون فولت ، علـــــى ذرات عنصر الحديد ٥٦ لتتكون بذلك نُوَى مركبة للكوبلت ٥٧ في حالات مُثَـــارة مختلفة الطاقه . وبدراسة أطياف أشعة جاما الصادرة عن التفاعل تم تحديـــد أربع حالات رنين عند طاقات البروتونات ٣٧٢٠ ، ٣٧٢٧ ، ٣٧٧٤٠ و٣٧٩٣ ألـــف الكترون فولت حيث أثيرت أربع حالات لنواة الكوبلت ٥٧ هي ٩٦٨٢ ، ٩٦٨٩ ، ٩٧٣٤ و ٩٧٥٣ ألف الكترون فولت على التوالى .

درست هذه الحالات الاربع بِجَمْع أطياف لأشعة جاما الصادرة عن كل حاله ، ثـــم جُمِعت قياسات التوزع الزاوى لغزارة أشعة جاما لدى اضمحلال الحالات المُثَـــارة عند طاقات البروتونات ٣٧٢٠ ، ٣٧٧٤ و ٣٧٩٣ ألف الكترون فولت .

بعد تحليل القياسات السابقه ، تم حساب نِسَب التفرع لاضمحلال كـــــل الحالات الاربع المشارة في هذه الدراسة ،وتم تحديد قيمة الزخم الـــــزاوى ونوعية التماثل لتلك الحالات أيضـــــــا . فحُدِّد الزخم الزاوى ب $\frac{9}{2}$ وتماثـل ايجابي للحالتين ٩٦٨٢ و ٩٦٨٩ ألف الكترون فولت ،و ب $\frac{5}{2}$ وتماثل ايجابـــي للحالتين ٩٧٣٤ و ٩٧٥٣ ألف الكترون فولت .

ونظرا لكون نواة الكوبلت ٥٧ مناظرة لنواة الحديد ٥٧ فقد تمَّ التعرُّف على الحالتين ٩٦٨٢ و ٩٦٨٩ ألف الكترون فولت ككسرتين كلاهما مناظرة للحالـــة ٢٤٥٥ ألف الكترون فولت من الحديد ٥٧ ذات الزخم الزاوى $\frac{9}{2}$ والايجابيـــــة التماثل . أما الحالتين ٩٧٣٤ و ٩٧٥٣ ألف الكترون فولت فأيضا تم التعـــرُّف عليهما ككسرتين كلاهما مناظرة للمستوى ٢٥٠٦ ألف الكترون فولت من الحديـــد ٥٧ ذات الزخم الزاوى $\frac{5}{2}$ والايجابية التماثل . وأخيرا تم تحديد الحالتيـــن ٤٥٨٦ و ٤٦٧٥ ألف الكترون فولت كنظيرتين سفليتين ، الأولى للحالتيـــن $\frac{9}{2}$ موجبه التماثل والثانية للحالتين $\frac{5}{2}$ موجبة التماثل أيضـــا .

ACKNOWLEDGMENTS

I am deeply indebted to the University of Petroleum & Minerals (UPM) for the constant support of this work throughout all stages of its performance.

I am also grateful to Dr. Salah El-Kateb for the endurance and the help he showed as my Thesis Advisor. Thanks are also due to Drs. Darwish Ahmad Darwish, Asad Abdallah and Ahmed Hussein for their encouragement and being members of my thesis committee.

I also thank Drs. George Vourvopoulos and Themis Paradellis for their help and the interest they showed during the experimental measurements of this work.

Comments from the Physics faculty members and help from the Physics Department Chairmen are highly appreciated and my thanks are due to all of them. Thanks are also due to Mr. Mohammad Azam Shad for the excellent job he did in typing this thesis.

Finally, I wish to express my gratitude to all members of my family for their encouragement and understanding.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1. General:

The major breakthrough in nuclear physics was brought about by the work of the British physicist James Chadwick (1) in the Cavendish Laboratory, where he discovered that when beryllium was bombarded by α-particles, it released an unknown chargeless deep penetrating radiation which is capable of ejecting protons from other nuclei. Chadwick published his work in February 1932 describing the new chargeless particle for which he gave the "neutron" as a name. Later, Chadwick (2) was able to find that the mass of the neutron is only slightly larger than that of the proton. It was then concluded that nuclei consist only of protons and neutrons, with both of them to be regarded as the fundamental constituents of the nucleus (3,4). The discovery of neutron paved the way for the study of the forces within the nucleus of the deuteron (5,6). Another subatomic particle, the positron (7) was postulated by Dirac (8) in 1930 and then experimentally reported by C.D. Anderson (9) in 1932. The discovery of the positron made possible for physicists to neatly explain the mechanism of β-decay (10).

The year 1932 also gave birth to the first particle accelerator, which was the voltage multiplier of Cockcroft and Walton (11). Later on also Van De Graaff introduced his electrostatic generator (12), and by the year 1936 the Cyclotron of Lowrence and Livingston was able to accelerate protons, deuterons and α-particles to energies as high as several millions of electron volts.

The idea of charge symmetry was postulated by Heisenberg in his first paper on the proton-neutron model of the nucleus (13). He considered the forces acting between pairs of neutrons to be almost equal to those between pairs of protons. He also concluded that the variation of charge mass ratios of stable elements through the periodic table was due to the electrostatic repulsion between protons. In light nuclei where electrostatic forces are less pronounced the ratio N/Z is almost one. The charge symmetry hypothesis meant that all non-electrical forces are completely symmetrical between neutrons and protons. Quantitative applications were predicted for charge symmetry and experimental tests for its validity started in 1936 by the study of binding energy differences in mirror nuclei (as we will see later in this chapter). One of the early works on nucleon-nucleon forces was the proton-proton scattering experiment of Tuve et al. (14); as a result of this experiment Breit

et al. (15) were able to show that proton-proton and neutron-neutron interactions are similar when taken over the same energy range. The similarity of non-electrostatic forces between protons to that between a proton and a neutron, together with the charge symmetry principle gave the hypothesis of charge independence : interactions between all pairs of nuclear particles are the same (with the exception of electrostatic forces). The hypothesis of charge independence provided the direct linkage between elementary particle physics and nuclear physics. The conservation laws of isobaric spin and strangeness in elementary particle physics are direct extensions of the symmetry borne in the charge independence hypothesis in nuclear physics. In both classical and quantum physics, symmetry phenomena always imply some conservation laws. In quantum physics new quantum numbers are introduced for every symmetry, where these numbers give the eigenvalues of the conserved quantity. Charge independence and charge symmetry introduced new physical symmetries that should be expressed in new conservation laws and corresponding quantum numbers. In 1937 and 1939 Wigner (16,17) studied the properties of nuclear states implied by charge independence. Selection rules were derived later on by Adair (18) and Kroll et al. (19). Wigner (16,17) used Heisenberg's concept (13) of the neutron and proton as two states of a single particle,

the nucleon, and generalized the charge independence hypothesis into the formalism of isospin (isobaric) spin of nuclei. The isospin formalism is identical to that of physical spin. An abstract vector operator $\vec{t}$ in the abstract isospin spin space is quite analogous to the spin vector operator in physical spin space, and hence an eigenfunction of $\vec{t}$ will have an isospin quantum number which gives the "length" of $\vec{t}$ from the relation:

$$|\vec{t}|^2 = t(t + 1)$$

There are $2t + 1$ eigenfunctions with isospin spin t each has a different value of t_3, where t_3 is the component of $\vec{t}$ along an abstract direction in space called the charge axis. Treating the proton and the neutron as two charge states of a nucleon means that they both have their isotopic spin equal to 1/2. The possible values of t_3 now are $\pm$ 1/2, and it is arbitrary which of the nucleons takes the positive and which takes the negative. However, in nuclear physics, it is the convention that the neutron state is assigned the positive t_3 and the proton is assigned the negative value of t_3. The total isospin operator of a system of nucleons $\vec{T}$, is obtained by vectorially summing up the isospin operators of all the constituents of the system.

$$\vec{T} = \sum_{i=1}^{A} \vec{t}_i \quad (A \text{ number of nucleons})$$

Hence, $T_3 = \sum_{i=1}^{A} t_{3i} = \frac{N - Z}{2}$, where N is the number of neutrons and Z is the number of protons in a system of A nucleons. The sign convention chosen above makes the values of T_3 to be non-negative for all stable nuclei except ^3He and the proton. A strong support for the isotopic spin formalism comes from the experimental measurement of binding energy difference between mirror nuclei. One of the early works in this regard was the investigation of the positron decay of a number of elements having Z protons and Z-1 neutrons into the mirror nuclei having Z-1 protons and Z neutrons. Fowler et al. (20) bombarded several elements with 1 MeV deuterons. They then measured the maximum energies of the positrons produced in the decay, and used it in determining the difference in binding energy ΔW between the pairs of mirror nuclei. Using several assumptions of which charge symmetry was the main one, they were able to attribute the binding energy difference entirely to electrostatic interaction of the excess charge in the (Z,Z-1) nucleus. However, they supported their findings by classically calculating the electrostatic interaction, and they suggested the formula for binding energy difference as

$$\Delta W = (Z-1)\, e^2 \, (r^{-1})_{av}$$

$$= \frac{6e^2}{5r_o} \, (Z - 1) \, A^{-1/3}$$

where the nuclear radius $R = r_o A^{1/3}$ and if $r_o = 1.45$ fm

$$\Delta W = 1.20 \, (Z - 1) A^{-1/3} \text{ MeV}$$

Similar conclusions were arrived at by Bethe (21) about the binding energy difference between ^3H and ^3He. By the year 1941 many more binding energy experiments were performed, and pairs of atomic weights up to 41 had been investigated. Later on better values for the nuclear radius (r_o=1.2) were used in the calculations to verify the validity of charge independence (22,23).

With the exclusion of coulomb forces, energies of the excited states as well as the ground states will correspond in the pairs of mirror nuclei. These levels are expected to have the same spin and parity, they are isobaric analogue states (IAS). (See fig.1). In 1949 several research groups started investigating the existence of IAS. The first IAS was reported by Brown et al. (24) in ^7Be via the reaction $^{10}B\,(p,\alpha)^7Be$, the discovered level corresponds to the 479 keV level in ^7Li. The formalism of isobaric spin was applied to light nuclei, and many IAS were identified in doublets

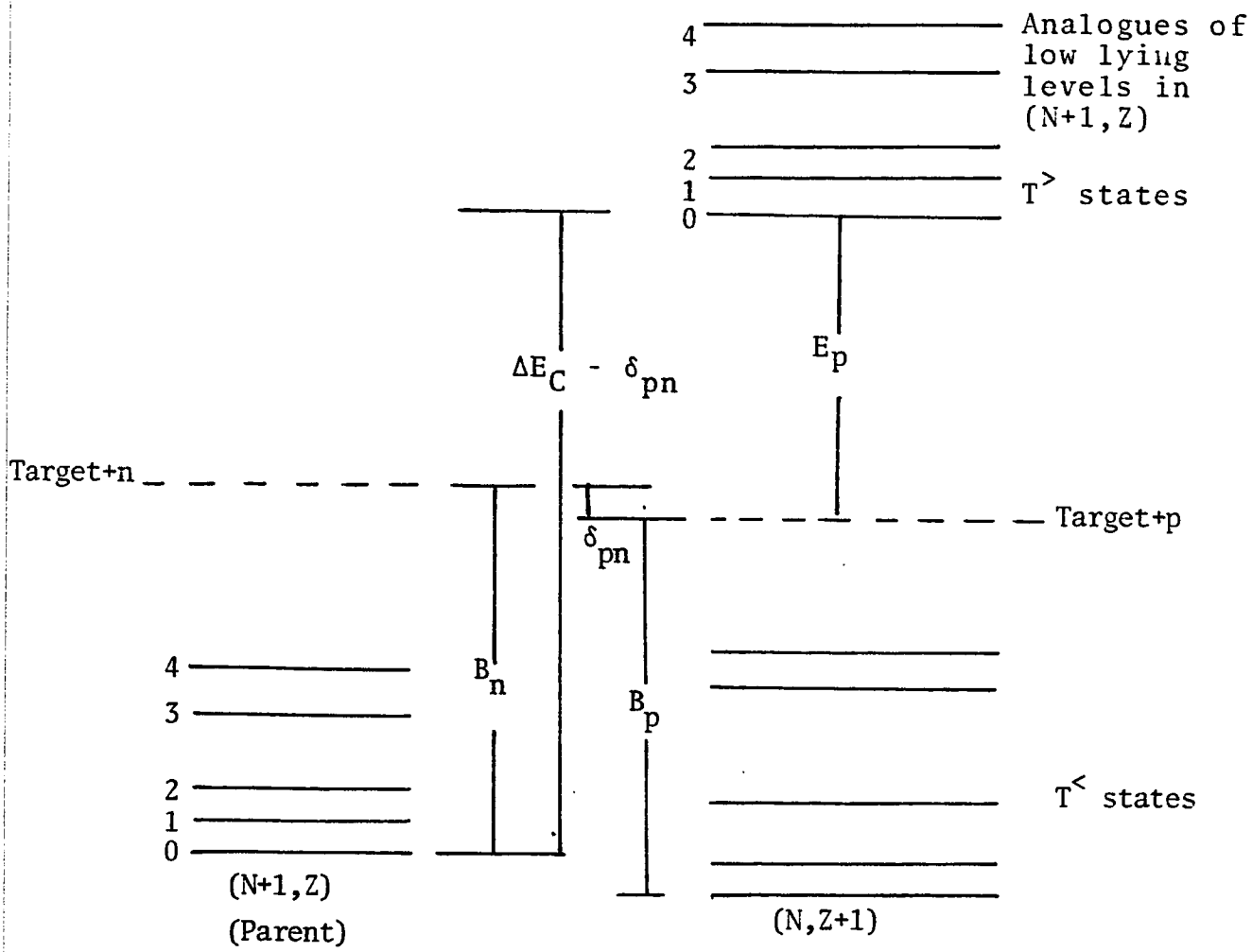


Figure 1 : The coulomb displacement energy relationship between analogue states.

and triplets of nuclei. The identification of IAS in light nuclei was easily accomplished because of their low excitation energies (3-9 MeV/nucleon), low level density and the relatively small coulomb interaction. However, because of the high level density and large coulomb forces in medium and heavy mass nuclei, researchers started to doubt the validity of isobaric spin formalism in that range of nuclei.

Anderson et al. (25-27) studied the ^{51}V (p,n)^{51}Cr reaction and concluded that isospin might be a well qualified quantum number over almost all of the nuclei. From that time on many experiments and theoretical studies supported the validity of isospin formalism even in nuclei as heavy as ^{137}Cs (see ref. 28 and references therein).

Resonant scattering of protons, (p,n) charge exchange and (p,γ) radiative capture reactions have provided most of the available data on isobaric analogue resonant states in medium and heavy mass nuclei. The isobaric analogue resonances (IAR) in nuclei were first observed in the (p,n) and proton elastic scattering cross section measurements by a group of Florida State University (28,29). Robson (30) using the quantitative interpretation of Lane (31) pertaining to the (p,n) reaction showed that analogue states could be observed in compound nuclei.

Investigations of analogue resonances in light nuclei (32) via (P,γ) and (P,P) reactions has provided useful information about the characteristics of these resonant states. The initial observations of the gamma-ray decay of analogue states in light nuclei e.g. ^{31}P and ^{35}Cl indicated that electromagnetic transitions had a simple character corresponding to strong M1 between analogue states of given spin and parity ($T^{>}$) and antianalogue states of the same spin and parity ($T^{<}$). In addition, these resonances also were observed to have a large reduced proton width and a large γ-ray width (32).

In 1969 and 1970 Maripuu (33-35) concluded that such strong M1 transition between analogue and antianalogue states was a very special case which showed up clearly in light nuclei i.e. in the 2s-1d shell nuclei. Maripuu (33) first noted that strong M1 transitions from analogue to anti-analogue states were confined to single particle states with $J = \ell+\frac{1}{2}$ while those between states with $J = \ell-\frac{1}{2}$ were reduced in strength. Maripuu (34,35) also noted that excitations of states with mixed character (small single particle strength) would not be strongly excited by(P,γ) reactions and when excited would have significantly reduced M1 strengths. The reduction of such M1 strength was explained as a result of the core polarization in the wave function describing the state. The $g_{9/2}$ analogue resonances have been investigated using (P,γ)

reactions on several 1f-2p shell medium mass (even-even and odd-even) target nuclei (36,37). In these nuclei the M1 strength in the $g_{9/2}$ analogue-antianalogue transitions reaches a maximum in the middle of the shell and tends to fall off on either side (38). Such reduction of M1 strength has been qualitatively interpreted as a result of core polarization as well as mixing between $T^{>}$ and $T^{<}$ states.

1.2 Present Status of the Problem:

The theoretical interest in the study of Cobalt isotopes is implied by their location in the vicinity of the doubly magic ^{56}Ni, they have one proton in the $1f_{7/2}$ subshell and along the series of the cobalt isotopes the $1f_{7/2}$ neutron has its closure (39). Shell model and other theoretical calculations were performed for the cobalt and many other isotopes in the same range of mass number (40-43).

The levels of ^{57}Fe and ^{57}Co have been investigated experimentally by several research groups via variety of reactions (44,45).

Isobaric analogue states in ^{57}Co corresponding to levels up to E =1725 keV state in the ^{57}Fe parent nucleus have been identified via (P,γ), (P,P) and (^{3}He,d) reactions

(46-55). The M1 strength for the observed analogue resonances in ^{57}Co were strongly reduced compared to the 2S-1d shell nuclei. Such reduction was interpreted as a result of core polarization effects (54-55).

Recently the decay of the $g_{9/2}$ IAR in ^{57}Co has been investigated through a (P,γ) reaction by two different groups (Fodor et al. (56) and Rangacharyulu et al. (57). Both groups have examined independently the energy region where the $g_{9/2}$ analogue states in ^{57}Co are expected. However, both groups disagreed on the number of $g_{9/2}$ fragments. In a high resolution experiment, Watson et al. (58) using (P,P), (P,P`) and (P,P`γ) reactions on ^{56}Fe target identified five $g_{9/2}$ fragments at E_p = 3698, 3704, 3718, 3731 and 3751 keV. In another high resolution experiment, Arai et al.(59) using ^{56}Fe (P,P_o) reaction observed only one $g_{9/2}$ resonance at Ep = 3732 keV. The $d_{5/2}$ IAR fine structure has been investigated recently via (P,P), (P,P`) and (P,P`γ) on ^{56}Fe by Watson et al. (58) and ^{56}Fe (P,P_o) reaction by Arai et al. (59).

1.3 Present Study:

In spite of the marked interest in studying the characteristics and systematics of analogue resonances in medium mass nuclei, one can see that in the case of ^{57}Co

nucleus some of these characteristics and systematics have not been established. Moreover, because of the difficulties in identifying the number of $g_{9/2}$ IAR fragments in ^{57}Co through (P,γ) earlier experiments, another investigation appeared necessary to obtain more definitive information regarding the $g_{9/2}$ IAR in ^{57}Co via ^{56}Fe (P,γ) reaction. Furthermore, new information is presented in this thesis regarding the $d_{5/2}$ IAR.

The work presented in this thesis was accomplished by measuring the excitation function of the ^{56}Fe (P,γ) and ^{56}Fe (P,P'γ) reactions in the Ep = 3694 - 3855 keV range. This proton energy range is where one expects the excitation of the $g_{9/2}$ and $d_{5/2}$ IAR (fig.2). Gamma-ray spectra were measured at the E_p = 3720, 3727, 3774 and 3793 keV resonances and γ-ray angular distributions were taken at E_p = 3720, 3774 and 3793 keV resonances.

The experimental apparatus used to carry out this work along with the procedures followed in the data collection and analysis are presented in Chapter 2. The experimental results, their interpretation as well as the important conclusions which may be drawn from the analysis are presented in Chapter 3.

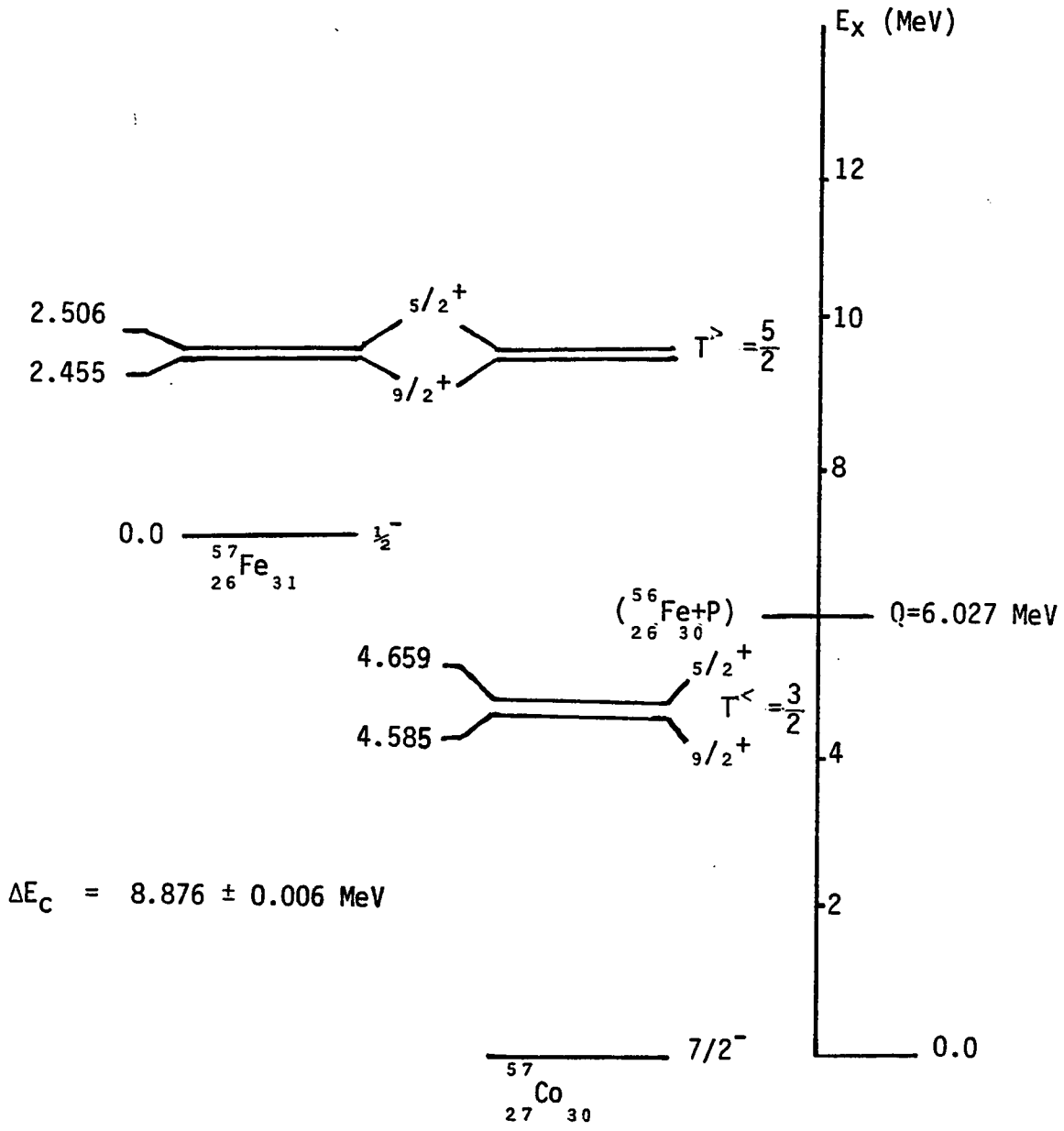


Figure 2. Correspondence between the isobaric analogue states and the levels of ^{57}Fe. This figure indicates the approximate excitation energy at which the $9/2^+$ and the $5/2^+$ resonances are expected.

CHAPTER 2

EXPERIMENTAL AND ANALYTICAL PROCEDURES

2.1 Proton Beam:

The $^{56}Fe\ (P,\gamma)^{57}Co$ reaction was studied using proton beam from the 5.5 MV $T_{11}/_{25}$ Tandem Van de Graaff accelerator at the Nuclear Research Center, Demokritos, Athens, Greece. An analyzing magnet is used to deflect the vertical ion beam produced by the accelerator into the horizontal direction. The feedback signal about irregularities in the ion beam is produced by a slit system situated near the exit of the analyzing magnet. Feedback signals are fed to the corona probe where they regulate and correct the accelerator terminal voltage. The overall system was capable of keeping the energy of the analyzed protons constant to within ±750 eV. In defining the shape and size of the beam, two tantalum apertures were used, both were 1.5 mm in diameter and they were located 40 and 90 cm away from the target chamber.

To minimize the difficulties arising from detector dead time, the beam current was kept between 1 and 3 microamperes, depending on the reaction yield at different values of proton energy. The exact beam energy was

determined by precise determination of the magnetic field necessary to bend the proton beam through the 90° analyzing magnet using a nuclear magnetic resonance (NMR) fluxmeter. The absolute value of the calibration constant for the NMR was checked using the Ep = 1747.6±0.9 keV resonance in the $^{13}C(P,\gamma)^{14}N$ reaction (60).

2.2 Targets and Target Chamber:

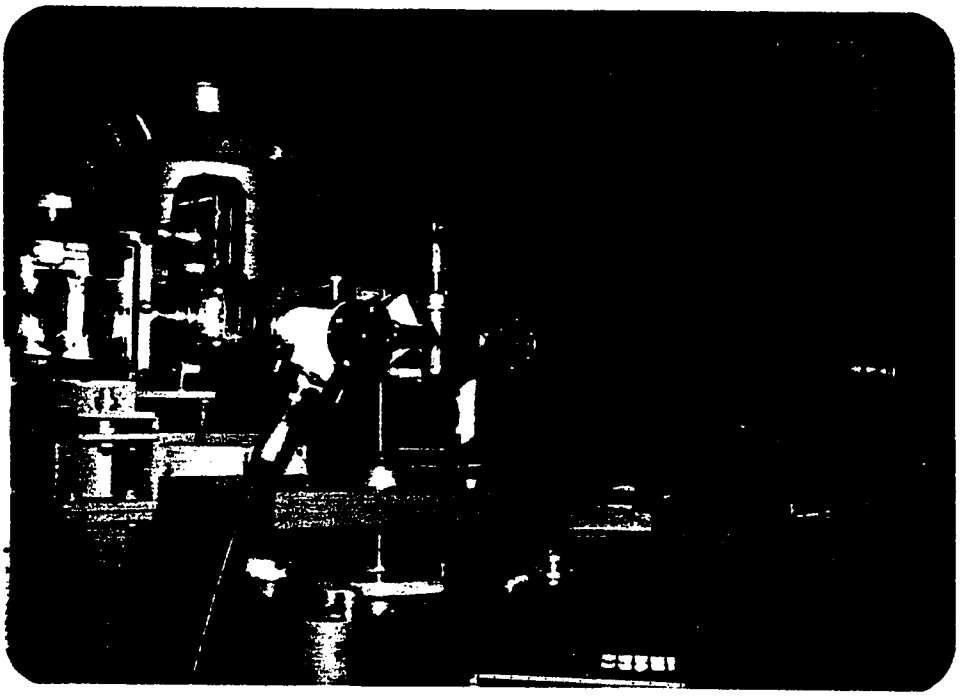
Two sets of ^{56}Fe (99,93% enrichment) targets were used in collecting the data. The first set was 26μg/cm² on 0.13 mm thick tantalum backing and the second set was a 20μg/cm² on a 20μg/cm² carbon and gold foil.

The target chamber was a 5 cm in diameter aluminum cylinder which was fixed at the center of the angular distribution table (fig. 3(a)). To minimize the unwanted reactions due to the scattering of protons at the target chamber walls, tantalum sheets were used as a lining on the inner walls of the target chamber. The target chamber was electrically insulated and used as a Faraday cup for measuring the beam charge. During the experiment targets were cooled using methanol water solution passing through tubings around the target holder.

During the measurement of the excitation function

Figure 3

(a) Target Chamber and Detectors



(b) Modified Target Chamber with Beam Extension

and γ-ray spectra, an extension tube (1 m long) was added to the beam line beyond the position of the target chamber (fig. 3(b)). This addition helped in reducing the background of unwanted contaminants and in lowering the dead time to within 5%.

2.3 Detectors and Electronics:

Three cylinderically coaxial Ge(Li) detectors were used to collect the data. The first has an active volume of 95 cm^3, an effective efficiency of 19.1% at 25 cm source to detector distance (relative to a 3x3 inch NaI(Tl) detector) and its energy resolution is 1.95 keV (FWHM) for the 1333 keV γ-ray from ^{60}Co source. The second detector has an active volume of 48 cm^3, a relative efficiency of 8% and an energy resolution of 1.87 keV (FWHM) for the 1333 keV γ-ray from ^{60}Co source. The third detector has an active volume of 45 cm^3 and an energy resolution of 2.2 keV (FWHM) for the 1333 keV γ-ray from ^{60}Co radioactive source.

The first (95 cm^3) detector was used as a movable while the second (48 cm^3) was used as a monitor in collecting most of the data presented in this thesis. At a later stage of data collection and due to some problems with the

energy resolution of the 95 cm^3 detector, the 48 cm^3 detector (movable) and the 45 cm^3 detector (monitor) were used in collecting some of the data.

Figure 4 shows the block diagram of the detectors and the electronics which were used in collecting the data. Pulses from the detectors were stored either in a 4K TN1700 multichannel analyzer or in an online PDP-15 computer. All data was recorded on magnetic tapes for subsequent analysis. The overall detection system was checked and calibrated using ^{60}Co and ^{22}Na radioactive sources.

2.4 Excitation Function and γ-Ray Spectra:

In all the measurements described in this section, the ^{56}Fe target was placed at 45° and the Ge(Li) detector (shielded) at 55° with respect to the proton beam direction.

The excitation function was measured over proton energy range Ep = 3694-3855 keV in steps of 1.6 keV using the 26μg/cm^2 target and the 95 cm^3 Ge(Li) detector. At each proton energy a γ-spectrum was collected for a charge of 200 μC, and four gates were selected to indicate the γ-yields. Table 1 shows the selected gates and their energy ranges. The reproducibility of the excitation function was

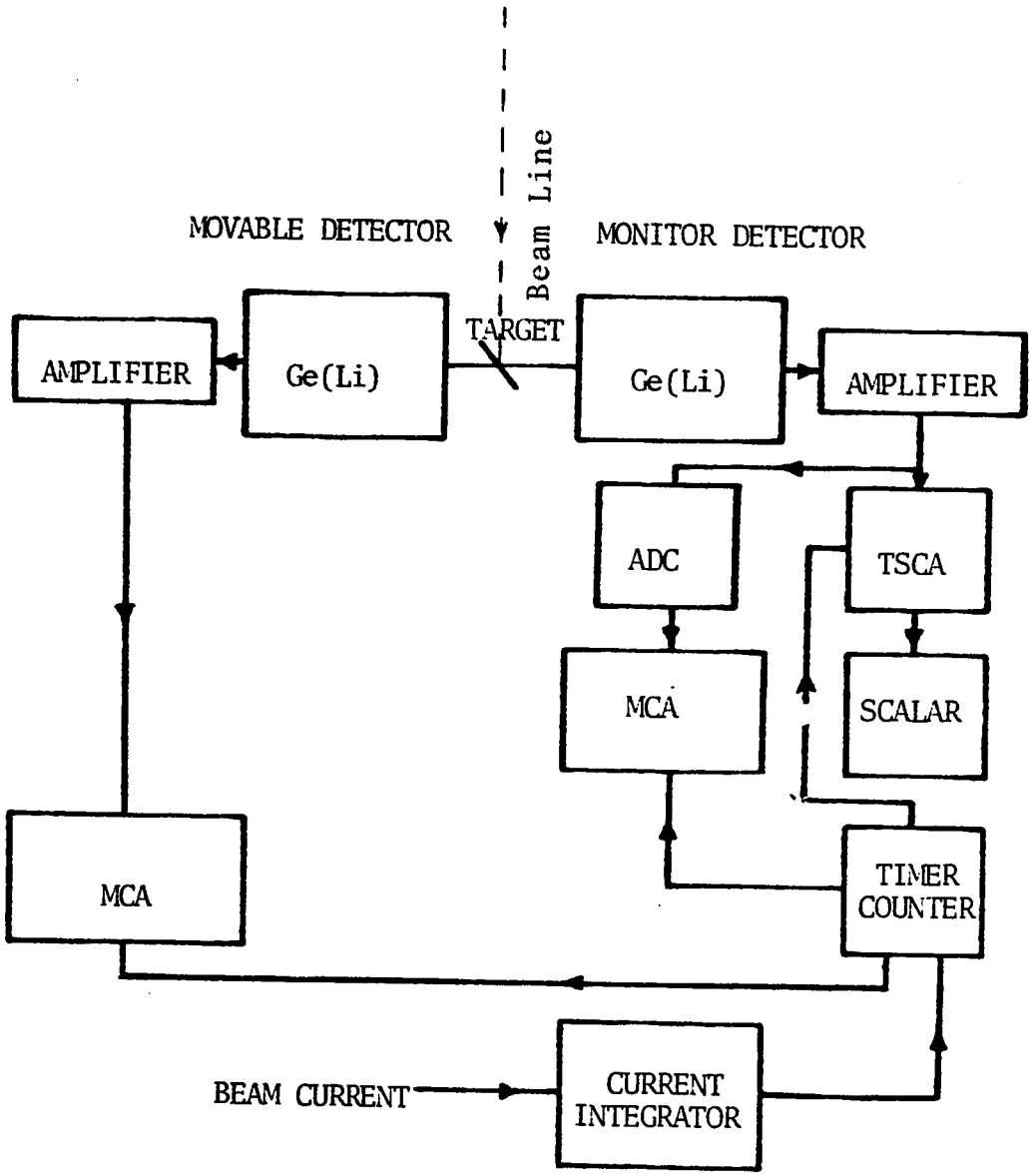


Figure 4 : Detectors and Electronics Block Diagram.

TABLE 1 : Selected Gates for γ-Ray Yield in the Measurement of the Excitation Function

Gate Number	γ-Ray Energy Range	Reaction (Transition)
1	8.6 - 10.0 MeV	$^{56}Fe(P,\gamma)^{57}Co$ ($g_{9/2}$+IAR→G.S.) ($d_{5/2}$+IAR→G.S.)
2	840 - 855 keV	$^{56}F(P,P'\gamma)$ (846 keV(2+))
3	4.0 - 5.0 MeV	$^{56}Fe(P,\gamma)^{57}Co$ ($R\rightarrow T_{<}$)
4	7.0 - 10.0 MeV	$^{56}Fe(P,\gamma)^{57}Co$ (R→G.S. and R→low energy states)

checked several times using the 20μg/cm² target and the 48 cm³ Ge(Li) detector.

Gamma-ray spectra were detected using the 26μg/cm² ^{56}Fe target and the 95 cm³ Ge(Li) detector at the Ep=3720, 3727, 3774 and 3793 keV resonances. Off-resonance spectra were also measured at Ep = 3712 and 3786 keV to allow for background subtraction, proper analysis of the spectra and establishing the decay schemes. The γ-spectra at Ep=3774 3793 and 3786 keV were also measured using the 20μg/cm² ^{56}Fe target and the 48 cm³ Ge(Li) detector.

Gamma-ray spectra were calibrated using ^{60}Co and ^{22}Na radioactive sources. The presence of the 6129.41±0.18 keV γ-ray from the $^{19}F(P,\alpha\gamma)^{16}O$ reaction as a contaminant (61) served as a calibration point for the higher energy portion of the spectra.

Peaks on the γ-spectra were identified and their centroids were determined. Sums were obtained for each of the photo-peak, single and double escapes of each γ-ray after proper subtraction of background. The sums of γ-yields were then corrected by subtracting the off-resonance contribution and correcting the net intensity of each γ-ray for detector efficiency. The decay scheme for each resonant state was then established and their branching ratios were

determined. The error in the decay scheme branching ratios ranges from 1 to about 2%. All of the γ-ray spectra analysis was accomplished using a FORTRAN program (see appendix C) on the UPM 3033 IBM Computer.

2.5 Gamma-Ray Angular Distributions:

Gamma-ray spectra were measured at four angles between 0° and 90° relative to the proton beam direction at each of the Ep = 3720, 3774 and 3793 keV resonances. The movable detector (shielded and collimated) was placed at 7 cm distance from the target while the monitor detector (shielded) was at 90° with respect to the beam direction and situated 4 cm from the target.

The gamma-ray angular distribution at the Ep=3720 keV resonance was measured using the 26μg/cm^2 ^{56}Fe target, the 95 cm^3 Ge(Li) detector (movable) and the 48 cm^3 Ge(Li) detector (monitor). For the other two resonances ^{56}Fe target of 26μg/cm^2 was used, the 48 cm^3 Ge(Li) detector (movable) and the 45 cm^3 Ge(Li) detector (monitor).

The anisotropy of the angular distribution table was measured using the 844 keV (2^+) γ-ray arising from the ^{27}Al(P,P`γ) reaction which has an isotropic angular distribution. The anisotropy correction resulted from such

measurement was found to be within 1% which was used in correcting the angular distribution data.

The sum of the areas under the full energy, single and double escape peaks after proper background subtraction was taken to be proportional to the γ-ray intensity. These areas were normalized with respect to the monitor and corrected for the anisotropy of the angular distribution table.

The measured intensities obtained at the four angles were fitted using a least squares procedure to the theoretical distribution described by the factored formalism of Harris et al. (62). The angular distribution data presented here were analyzed with the aid of a computer program which is a simple version of the program discussed by Hyder et al. (63). The general correlation function in this program is given in terms of population parameters defining the relative populations of the magnetic substates of the state being populated in the reaction. For unpolarized protons bombarding a spin-zero target, as is the case for $^{56}Fe(P,\gamma)^{57}Co$ reaction studied here, only one parameter (the multipole mixing ratio δ) enters the least squares fit of the experimental data to the theoretical expressions (appendix A).

The angular distribution results were analyzed to determine those spins and mixing ratios which minimize the function $Q^2 = (1/N) \sum_i \frac{1}{\Delta W_i} \{W(\theta i) - W^* (\theta_i)\}^2$ where N is the number of degrees of freedom, ΔW_i is the statistical error at each angle, $W(\theta_i)$ is the experimental counting rate measured at the ith angle θ_i and $W^* (\theta_i)$ is the theoretical counting rate at θ_i. The quantity $W^* (\theta i)$ is a function of the assumed spins and multipole mixing ratios.

For each possible spin assignment, the value of Q^2 was calculated for values of the multipole mixing ratio δ between $-\infty$ and $+\infty$. In actual practice the substitution $x = \arctan \delta$ is employed and values of Q^2 are calculated in 2° steps in x. In the case where there is a statistically significant agreement between the experimental data and the theory the minimum value of Q^2 is near unity. Hence acceptable solutions for the spin of the level and δ are those for which Q^2 can be made approximately equal to unity. The 0.1% limit at $Q^2 = Q_0^2$ for example indicates there is a statistical probability of 0.001 that the correct solution will have a measured value of Q^2 which is greater than or equal to Q_0^2. The estimates of errors associated with the mixing ratio δ were obtained at $Q^2 = Q_0^2$ corresponding to one standard deviation from Q^2_{min}.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Excitation Function:

Figure 5 shows the excitation function of the ^{56}Fe (P,γ) and ^{56}Fe(P,P'γ) reactions at the four different gates (mentioned earlier) in the Ep=3694-3855 keV range. From the excitation function there are four strong resonances at Ep= 3720, 3727, 3774 and 3793 keV. Other resonances in the 4-5 MeV gate are due to the 5270 keV contaminant γ-ray arising from the ^{18}O(P,αγ) reaction (64). The doublet at Ep=3720 and 3727 keV has been observed in earlier (P,γ) experiments by Fodor et al. (56) at Ep=3727 and 3735 keV, and by Rangacharyulu et al. (57) at Ep=3721 and 3728 keV.

3.2 Gamma-Ray Spectra and Angular Distribution:

From the excitation function it is clear that the four resonances at Ep=3720, 3727, 3774 and 3793 keV show transitions to the ground state ($J^{\pi}=7/2^{-}$) as well as other states around the 4-5 MeV excitation in ^{57}Co. These four resonances are discussed in the next two sections.

3.2.1 Resonances at E_p=3720 and 3727 keV:

Figure 6 shows the high energy portion of the γ-ray spectra at E_p=3720 and 3727 keV resonances as well as an off resonance spectrum at E_p=3712 keV.

The decay scheme of both resonances including the branching ratios is shown in fig. 7. As it is evident from the decay scheme both resonances populate high spin states in ^{57}Co. The state at 4586 keV could be identified with the one observed by Rosner and Holbrow (48) at 4600±20 keV from ^{56}Fe(^{3}He,d)^{57}Co reaction.

Table(2) shows a comparison between the γ-decay and branching ratios for both resonant states as a result of the present work and those reported earlier by Fodor et al.(56) and Rangacharyulu et al. (57).

Based on the mode of decay of the E_p=3720 keV resonance, transitions to the ground, 4586 and 2611 keV states have been used in the analysis of the angular distribution data. The least squares fits to angular distributions assuming different spin values for the three transitions studied at the E_p=3720 keV resonance are shown in fig. 8.

The Q^2 analysis of the R→G.S. angular distribution data (fig.9) indicates that the spin value for this

resonant state at E_x=9682 keV is either 5/2 (with δ = -0.176± 0.011) or 9/2 (with δ=0.035 ± 0.011).

Comparison of the mixing ratios δ, determined from fitting the theoretical expression to the angular distribution data with the single-particle transition strength (Weisskopf estimate), allows an upper limit to be placed on the multipolarity of the γ-radiation. It may be possible from such comparisons to reject some mixing ratios or even spin assignments. It is also sometimes possible to make a parity assignment on this basis. Table 3 summarizes the results of such comparisons for the three transitions studied at the E_p=3720 keV resonance.

Considering the resonance to G.S. transition (see table 3), a $J^{\pi}=5/2^{\pm}$ assignment can be ruled out when compared with the single particle transition strengths (Weisskopf estimate). A $J^{\pi}=9/2^{-}$ for this resonance is also very unlikely using a similar argument as above (see table 3). However, a $J^{\pi}=9/2^{+}$ is assigned for this resonant state at E_x=9682 keV.

Fodor et al. (56) have studied the same resonance and from their angular distribution measurement for the R→G.S. transition, a $J^{\pi}=9/2^{+}$ has been assigned, which is in

agreement with the present work. Rangacharyulu et al. (57) who investigated the same energy range ruled out a possible $J^{\pi}=9/2^{+}$ on the basis of the γ-ray mode of decay at this proton energy; consequently they did not attempt any angular distribution measurement.

On the basis of $J^{\pi}=9/2^{+}$ for the E_p=3720 keV resonance, the R→4586 keV Q^2-fits (fig. 10) indicate that the only acceptable spin value for the level at 4586 keV is 9/2 with δ = 0.035±0.02. Based on the Weisskopf estimate, a positive parity is very likely (see table 3) and consequently a $J^{\pi}=9/2^{+}$ is assigned to the 4586 keV level. This assignment is supported by the $^{56}Fe(^{3}He,d)^{57}Co$ data of Rosner and Holbrow (48) who identified an ℓ_p=4 at Ex=4600±20 keV in ^{57}Co. On similar basis Fodor et al. (56) inferred a $J^{\pi}=9/2^{+}$ for a level at 4585 keV.

Using $J^{\pi}=9/2^{+}$ for this resonant state, the R→2611 keV transition Q^2-fits indicate that a J=7/2 with δ=0.035±0.013 is the only acceptable spin value for the state at Ex=2611 keV in ^{57}Co. Figure 11 shows the results of the Q^2-fits for the R→2611 keV transition. From the Weisskopf estimate (see table 3) a negative parity is more likely, and a $J^{\pi}=7/2^{-}$ is assigned for the 2611 keV state. Previous (P,γ) experiments on ^{56}Fe targets failed to assign a unique spin value for this

state (44).

Concerning the E_p=3727 keV resonance, a $J^\pi=9/2^+$ is most likely based on the mode of decay of the resonant state at E_x=9689 keV. Angular distribution measurement at E_p=3727 keV resonance by Fodor et al. (56) and by Rangacharyulu et al. (57) resulted in a $J^\pi=9/2^+$ which agrees with the J^π value inferred from the decay scheme results discussed earlier. (see fig. 7).

3.2.2 Resonances at E_p=3774 and 3793 keV:

Figure 12 shows the high energy portions of the γ-ray spectra at E_p=3774 and 3793 keV resonances as well as an off-resonance spectrum at E_p=3786 keV. The decay of both resonances including the branching ratios is shown in fig. 13.

For the resonance at E_p=3774, angular distribution analysis was performed for transitions from the resonant state to G.S., 1378, 1757 and 4675 keV levels in ^{57}Co. Figure 14 shows the least squares fits of these angular distributions assuming different spin values.

For the R→G.S. transition, Q^2 analysis (fig. 15)

indicates that the spin of this resonant state could be either 3/2 or 5/2. However, comparison with the Weisskopf estimate (table 4) shows that the spin and parity of this resonant state at E_x=9734 keV is $\frac{5+}{2}$.

The Q^2 results of the 9734→1378 keV transition is shown in fig. 16. From the fitting, spin values of 3/2 and 5/2 are considered acceptable. However, when these values were compared with the Weisskopf estimate (table 4) a $J^\pi=\frac{5+}{2}$ for this resonance was assigned.

Figure 17 shows the Q^2 analysis for the 9743→1757 keV transition at the E_p=3774 keV resonance. Comparison of the experimental mixing ratio values with the Weisskopf estimate confirms the $J^\pi=\frac{5+}{2}$ for the resonant state at E_x=9734 keV (see table 4).

On the basis of $J^\pi=5/2^+$ for the resonant state at E_x= 9734 keV, the R→4675 keV Q^2-fit (fig. 18) indicated that a J=3/2 and 5/2 were acceptable for the 4675 keV state. However, the J=3/2 value was ruled out by comparison of the δ values with the Weisskopf estimate (table 4) and a $J^\pi=5/2^+$ was taken as most probable for the 4675 keV state.

For the resonance at E_p=3793 keV (E_x=9753 keV), angular distribution analysis was performed for transitions

from the resonant state to the G.S., 1897 and 4675 keV levels in ^{57}Co. Figure 19 shows the least squares fits of these angular distributions assuming different spin values.

The Q^2-fit (fig. 20) for the R→G.S. transition allows two possible spin values for the resonant state, 5/2 and 3/2. However, after comparison with the Weisskopf estimate (table 5) a $J^{\pi}=3/2^+$ or $5/2^+$ could be assigned to the E_x=9753 keV state.

Figure 21 shows the Q^2-fit for the R→1897 keV transition. Comparison of the mixing ratios from the Q^2 analysis with the Weisskopf estimate (table 5) indicates that a $J^{\pi}=5/2^+$ assignment for this resonant state is very likely.

The R→4675 keV transition was analyzed using the assigned $J=5/2^+$ for the resonant state at E_x=9753 keV. Comparing the results of the Q^2-fit (fig. 22) with the Weisskopf estimate (table 5), confirms the $J^{\pi}=5/2^+$ for the 4675 keV state assigned earlier.

3.3 Identification of Isobaric Analogue Resonances:

Identifying analogue states which are produced by

(P,γ) reactions, or which happen to be excited bound states of the nucleus can be particularly difficult when the analogue strength is split up and mixed into some other nuclear substructure. The identification may then depend on recognizing various features of the nuclear states, such as coulomb displacement energy (ΔE_C), common spins and parities for closely spaced levels in the parent nucleus.

Based on the coulomb displacement energy ΔE_C=8876± 6 keV (54) for the ^{57}Co-^{57}Fe pair the doublet at E_p=3720 and 3727 keV is identified as the split analogue of the E^*=2455 keV, $J^\pi=9/2^+$ parent state in ^{57}Fe. The state E=4586 keV in ^{57}Co is identified as the antianalogue $J^\pi=9/2^+$ state. The other two resonances at E_p=3774 and 3793 keV are identified as the fragmented analogue resonances of the E^*=2506 keV, $J^\pi=5/2^+$ state. Table 6 summarizes a comparison between the resonances found in the present work with those expected for analogues of ^{57}Fe states.

3.4 Summary and Conclusions:

As a result of the work presented in this thesis, spins and parities of the E_p=3720, 3774, 3793 keV resonances in ^{57}Co have been determined from angular distribution measurements. A $J^\pi=9/2^+$ has been assigned for the resonance at E_p=3720 keV, while a $J^\pi=5/2^+$ has been assigned for the

two resonances at E_p=3774 and 3793 keV. From the γ-spectrum and mode of decay a $J^\pi=9/2^+$ has been assigned for the E_p= 3727 keV resonance. Moreover, the spin and parity of the levels at E_x=2611, 4586 and 4675 keV in ^{57}Co have been determined as $J^\pi=7/2^-$, $9/2^+$ and $5/2^+$ respectively. Figure 23 summarizes the results presented in this thesis.

The spins and parities of these resonances along with their energy spacings as obtained from the ^{56}Fe(P,γ) ^{57}Co excitation function and the coulomb displacement energy ΔE_C=8876±6 keV have been used in identifying these resonances as analogue states to the 2455 keV ($J^\pi=9/2^+$) and the 2506 keV ($J^\pi=5/2^+$) states in ^{57}Fe. The resonances at E_p=3720 and 3727 keV ($J^\pi=9/2^+$) have been identified as the fragmented analogue of the 2455 keV ($J^\pi=9/2^+$) state in ^{57}Fe. The E_p=3774 and 3793 keV resonances have been identified as the fragmented analogue of the 2506 keV ($J^\pi=5/2^+$) state in ^{57}Fe.

The levels at 4586 keV ($J^\pi=9/2^+$) and 4675 keV ($J^\pi=5/2^+$) in ^{57}Co have been identified as antianalogue ($T^<$) states.

Concerning the doublet at E_p=3720 and 3727 keV, the present results indicate that the $g_{9/2}$ analogue resonance in ^{57}Co is split into two fragments contrary to earlier

results by Rangacharyulu et al. (57) who rejected the E_p= 3720 keV resonance from being a $g_{9/2}$ analogue candidate. However, the present results are in agreement with those reported by Fodor et al. (56).

In conclusion, the analogue to antianalogue M1 strength tend to be strongly reduced for both $g_{9/2}$ and $d_{5/2}$ analogue resonances in ^{57}Co compared to the 2s-1d shell nuclei. Such departure from the single-particle picture is a direct consequence of the core polarization effects on the antianalogue state. Admixture of core polarized components into the antianalogue state can be especially effective in reducing analogue to antianalogue M1 transition strength if both the odd particle and the perturbing core have $J=\ell+1/2$. The present work indicates that many of the properties of other lighter 1f-2p shell nuclei such as ^{49}Sc and ^{51}V are reproduced in the ^{57}Co nucleus. Similar investigation on ^{59}Co nucleus indicated that the $g_{9/2}$ IAR are severly fragmented to the extent that they escaped observation (66). Briefly the analogue antianalogue M1 strength reaches a maximum in the middle of the 1f-2p shell nuclei and tends to decrease on either side. Qualitatively such decrease in M1 strength near the closure of the $1f_{7/2}$ proton shell could be understood as a result of the increased core polarization with the increase of the mass number in this region of nuclei.

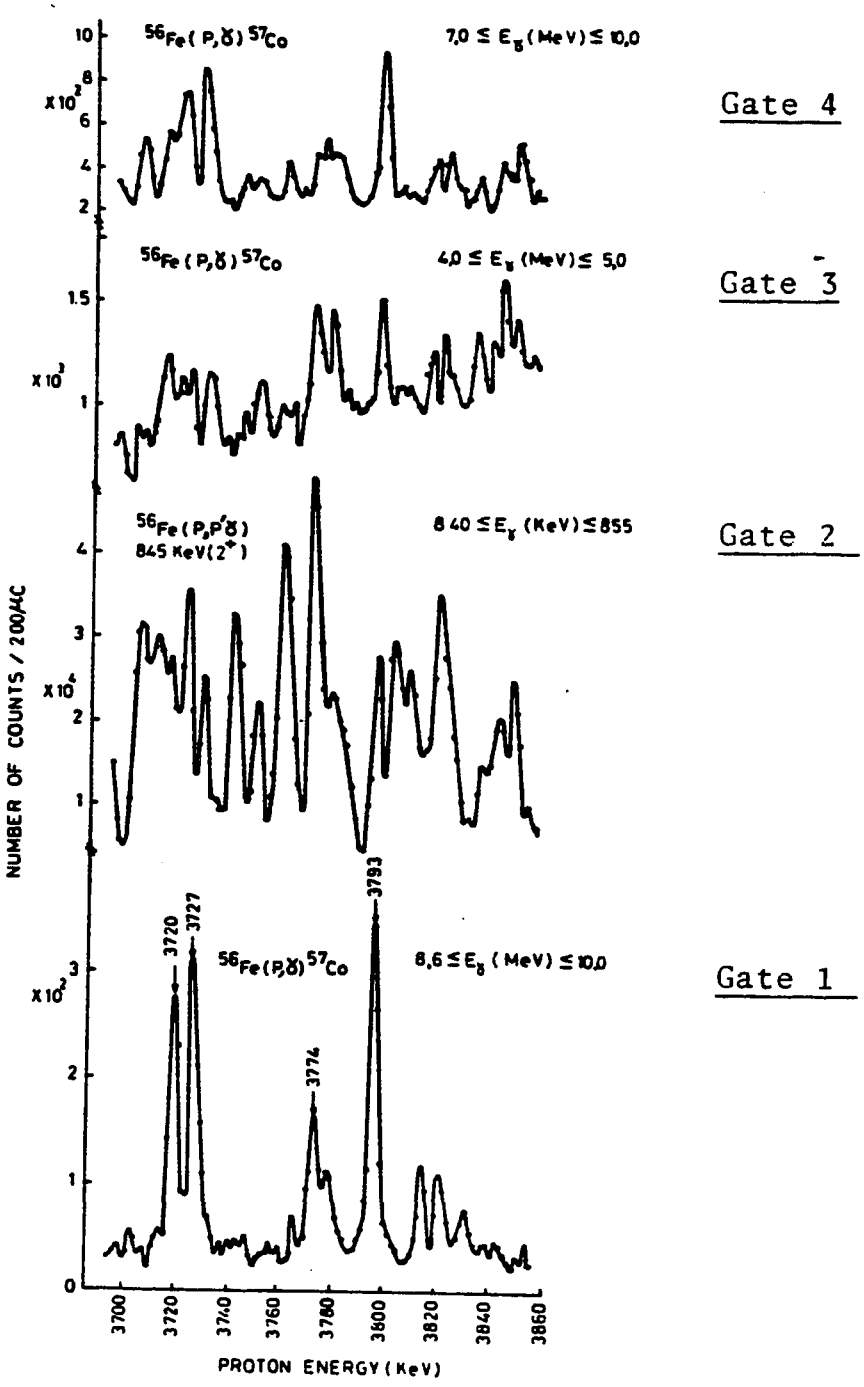


Figure 5 : Excitation function for Ep=3694-3855 keV. Four γ-ray energy gates are shown above. The target used in this measurement was 20 μg/cm^2.

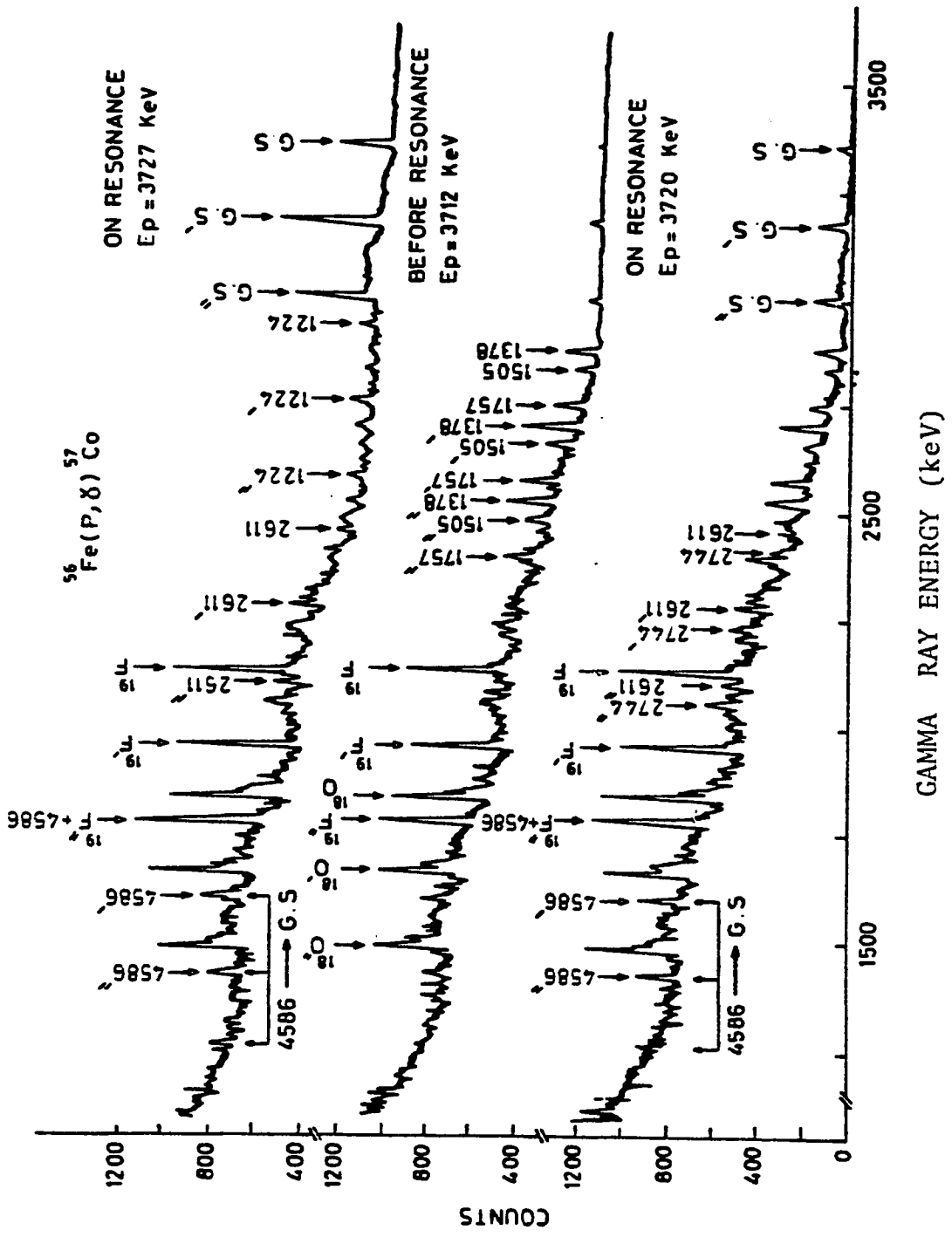


Figure 6 : High energy portion of the γ-ray spectra at the E_p=3720 and 3727 keV resonances and an off-resonance at E_p=3712 keV. All three spectra were measured with a 95 cm^3 Ge(Li) detector.

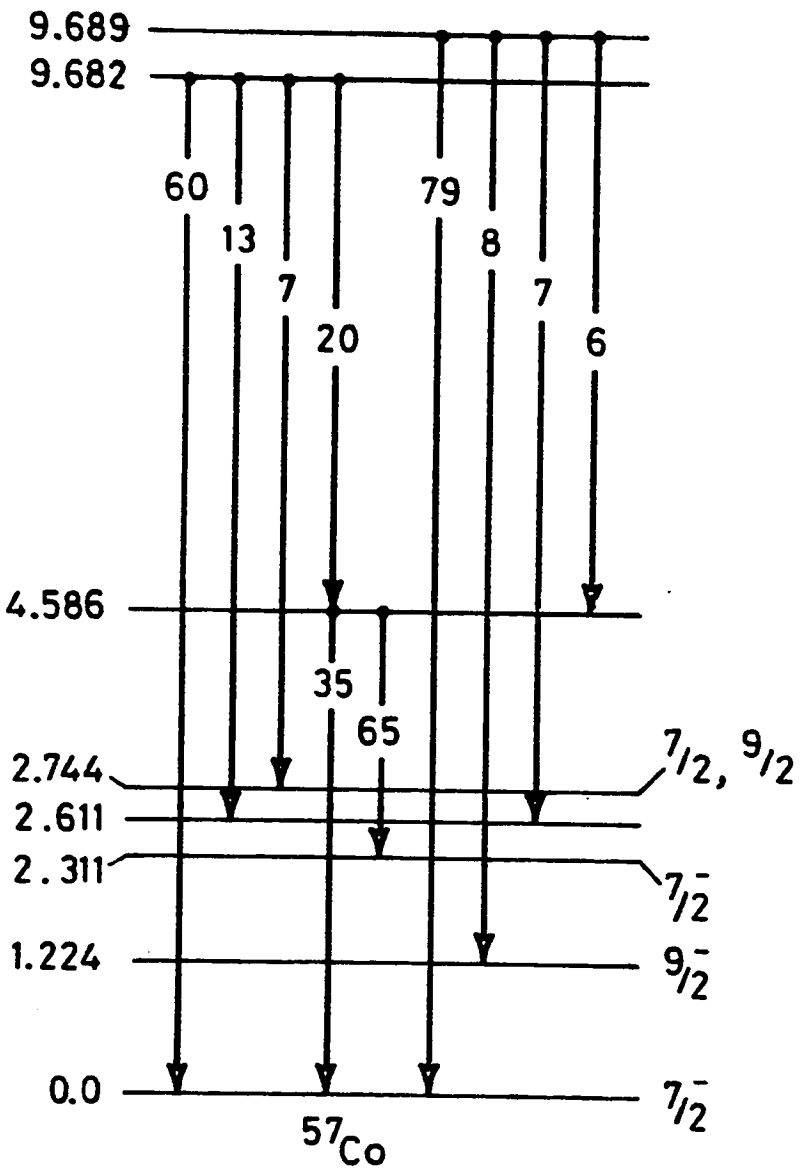


Figure 7 : The decay scheme of the resonances at E_p=3720 and 3727 keV.

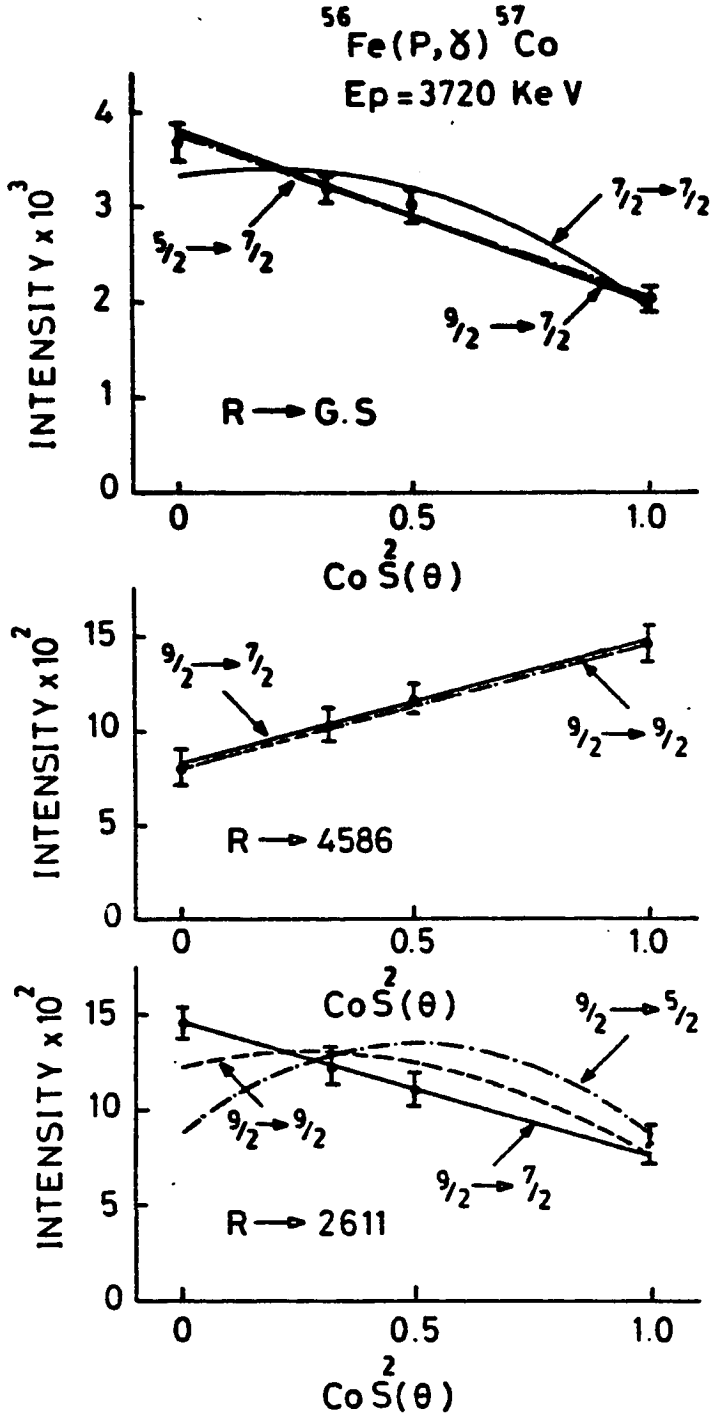


Figure 8 : Experimental angular distribution data and their Least Squares fits for Different spin Sequences.

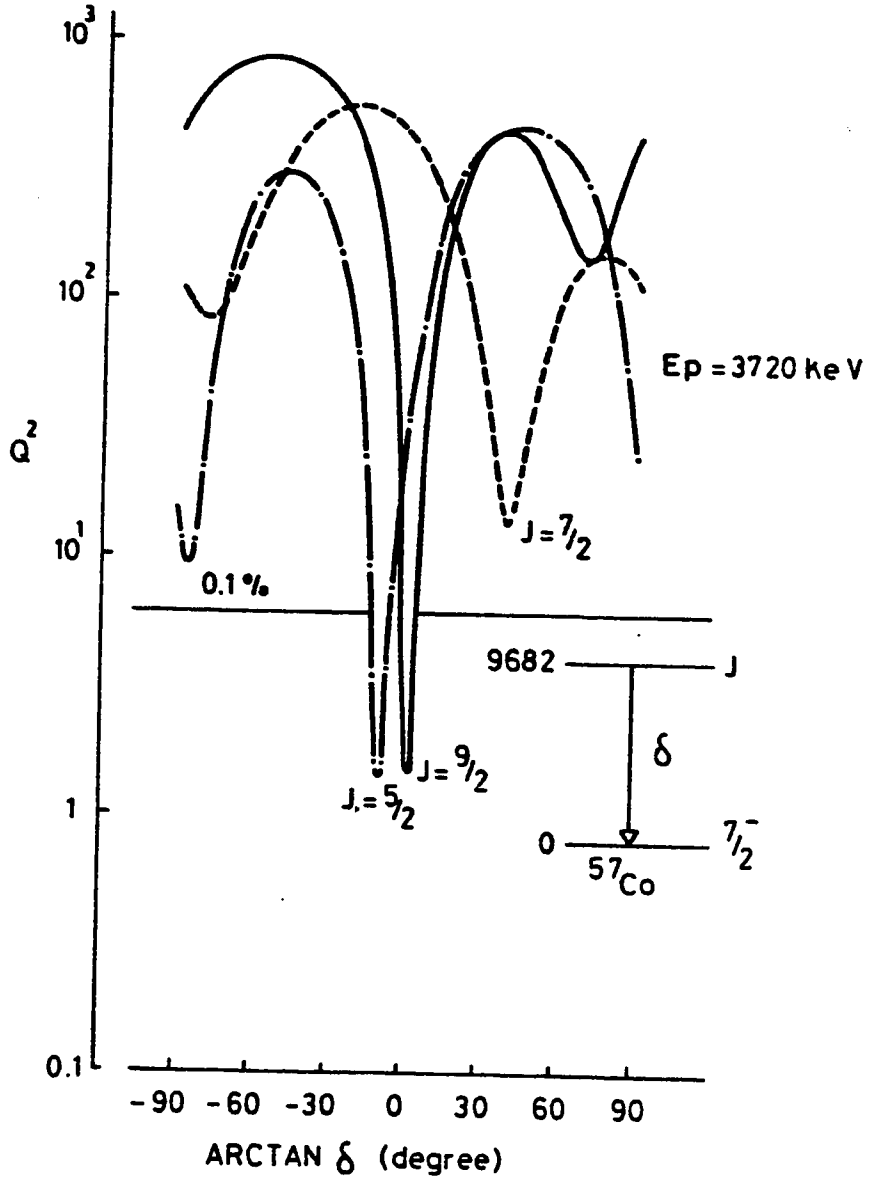


Figure 9 : Values of Q^2 versus arctan δ from fitting experimental angular distribution of R to G.S. transition to theory for different spin values.

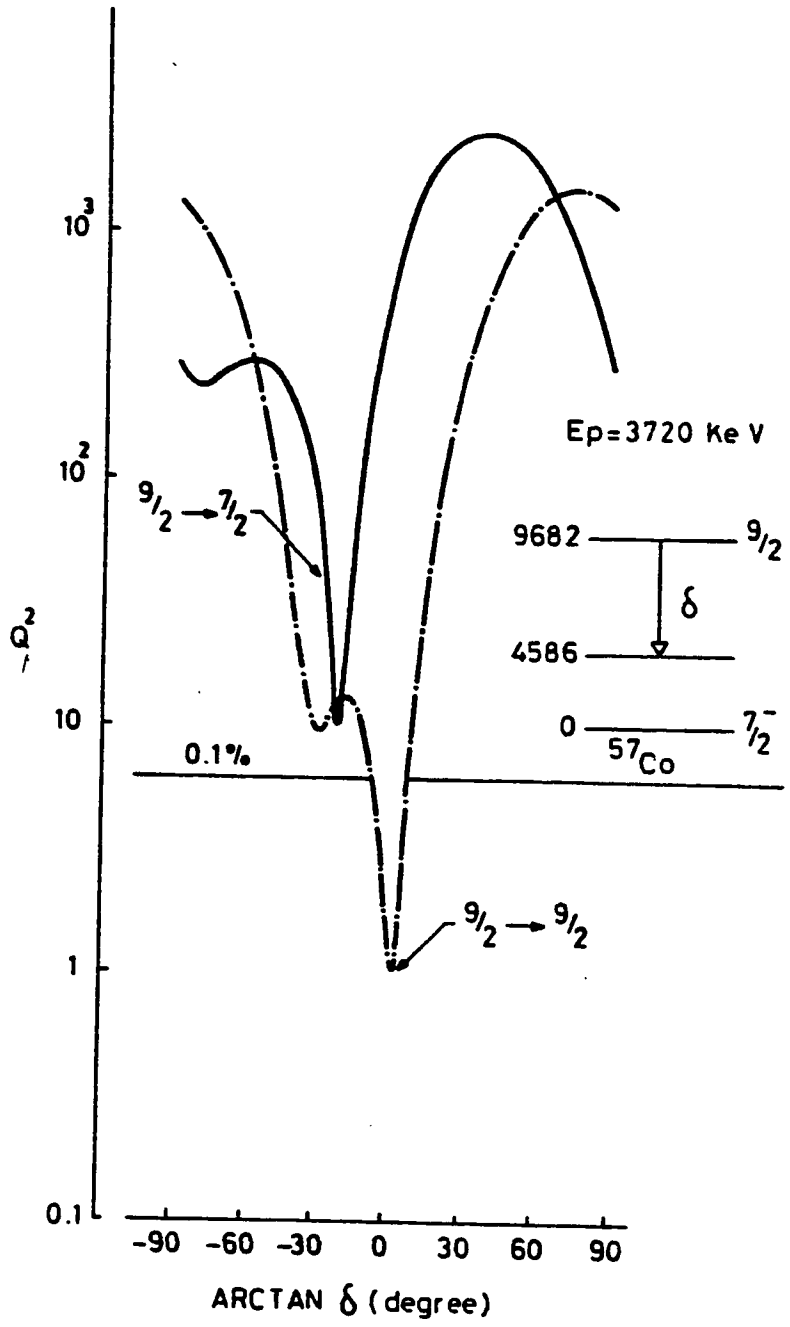


Figure 10 : Values of Q^2 versus arctan δ from fitting Experimental angular distribution of R to 4586 keV transition to theory for different spin values.

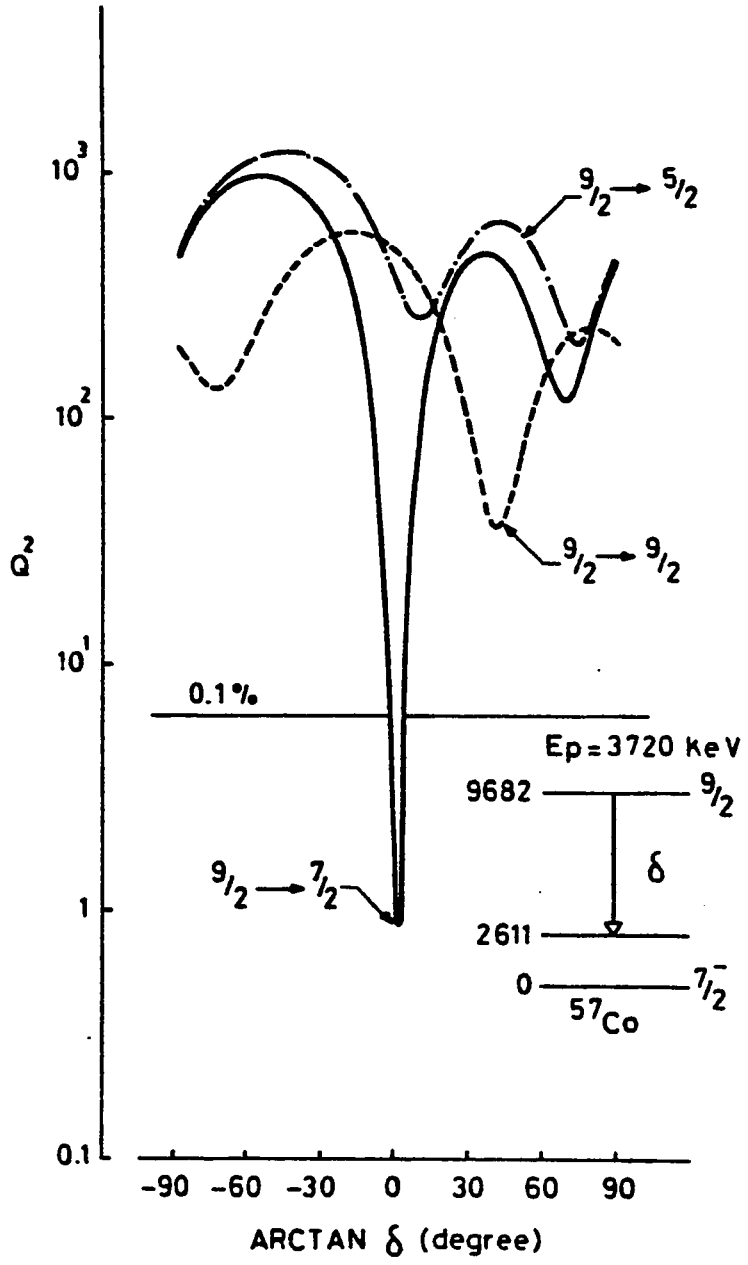


Figure 11 : Values of Q^2 versus arctan δ from fitting experimental angular distribution of R to 2611 keV transition to theory for different spin values.

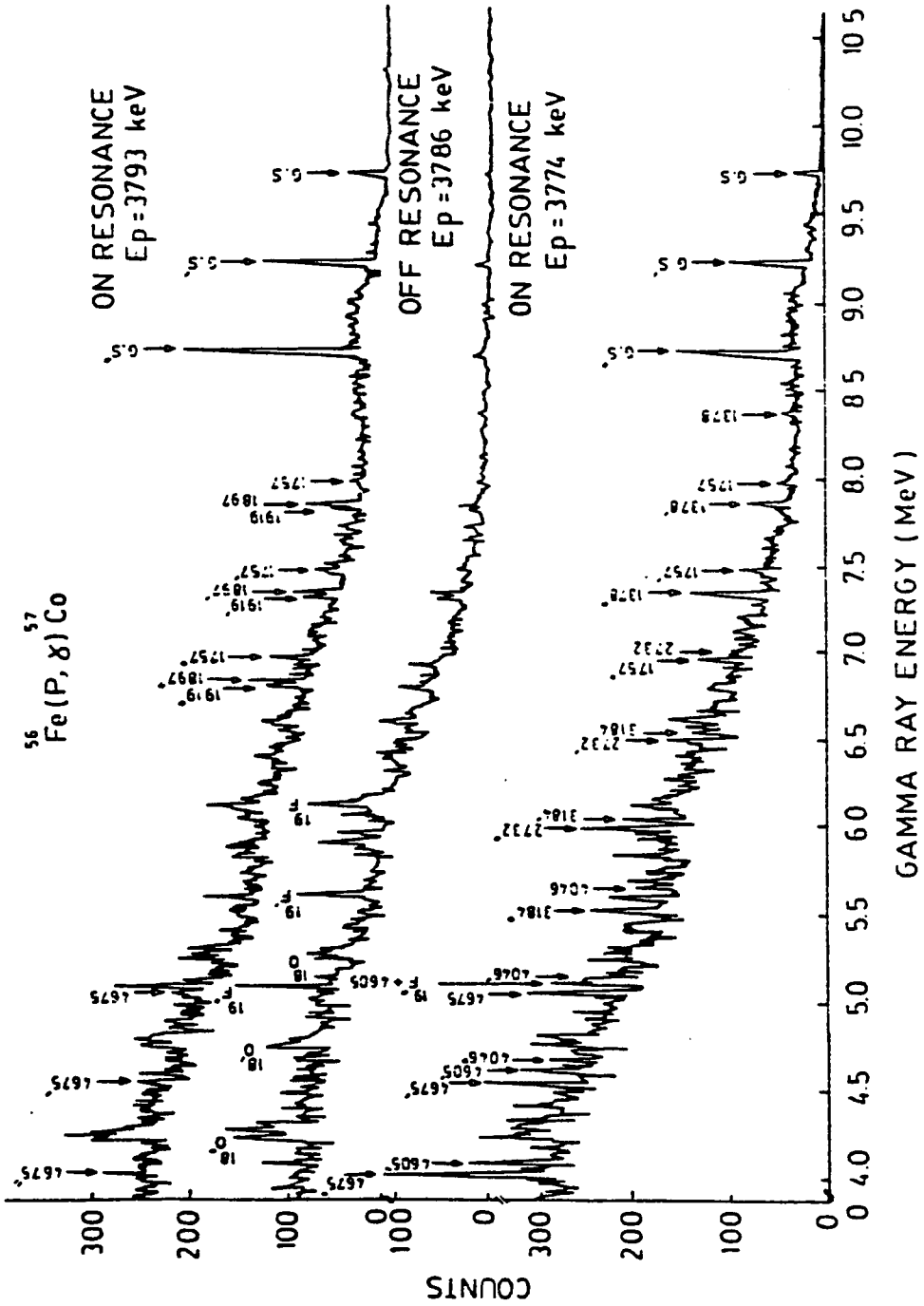


Figure 12 : High energy portion of the γ-Ray spectra at the E_p=3774 and 3793 keV resonances and an off-resonance at E_p=3786 keV. A11 three spectra were measured using a 48 cm^3 Ge(Li) Detector.

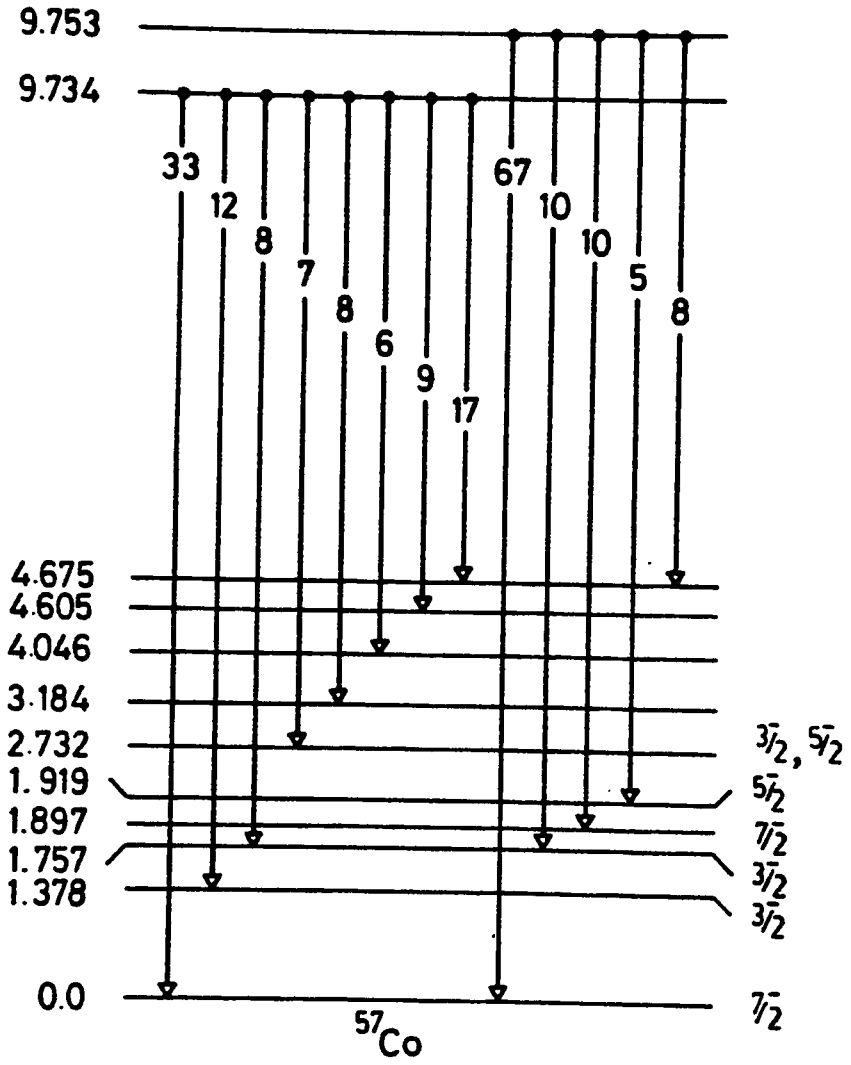


Figure 13 : The decay scheme of the resonances at E_p=3774 and 3793 keV.

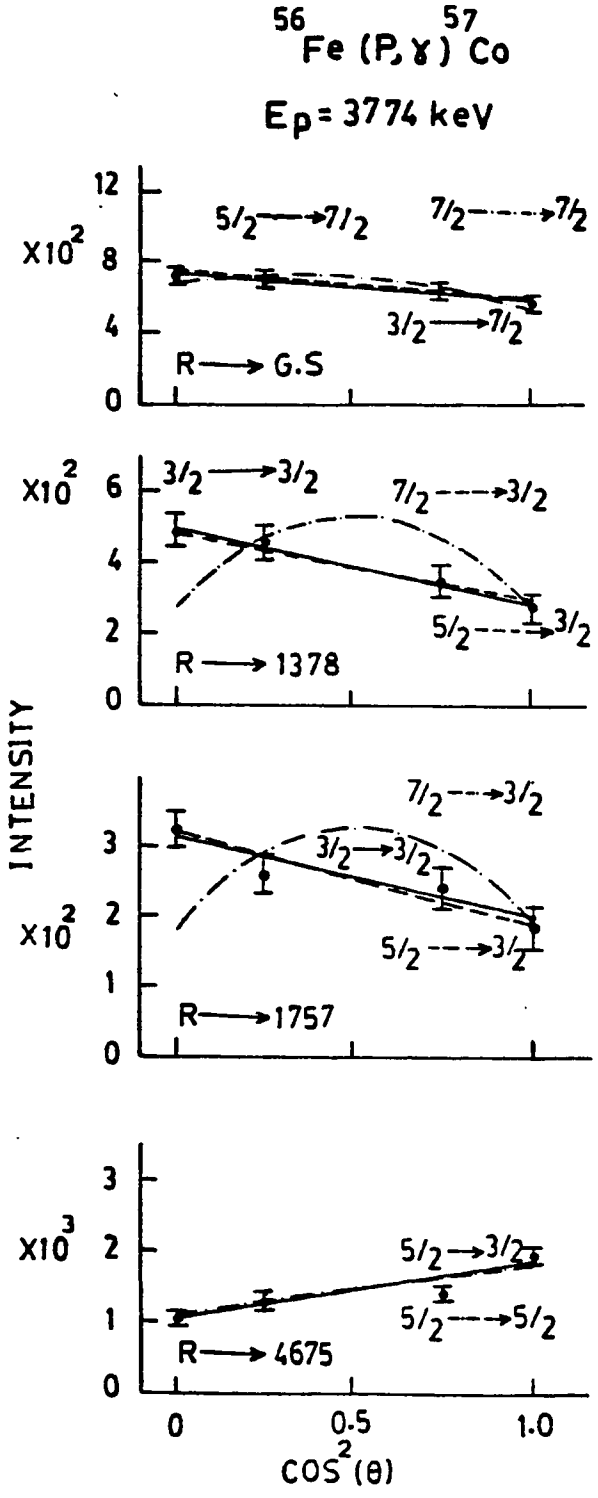


Figure 14 : Experimental angular distribution data and their Least Squares Fits to different spin sequences.

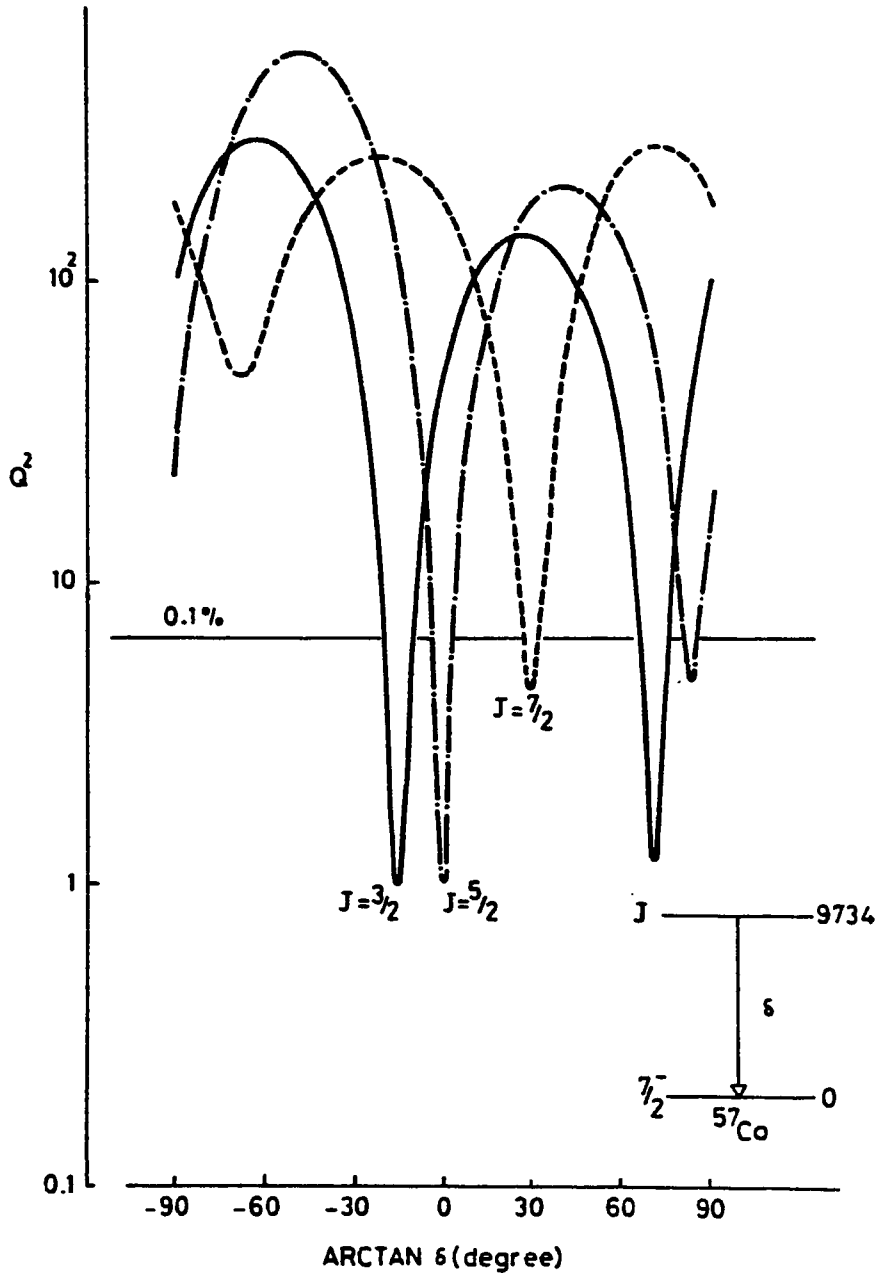


Figure 15 : Values of Q^2 versus arctan δ from fitting experimental angular distribution of R to G.S. transition to theory for different spin values.

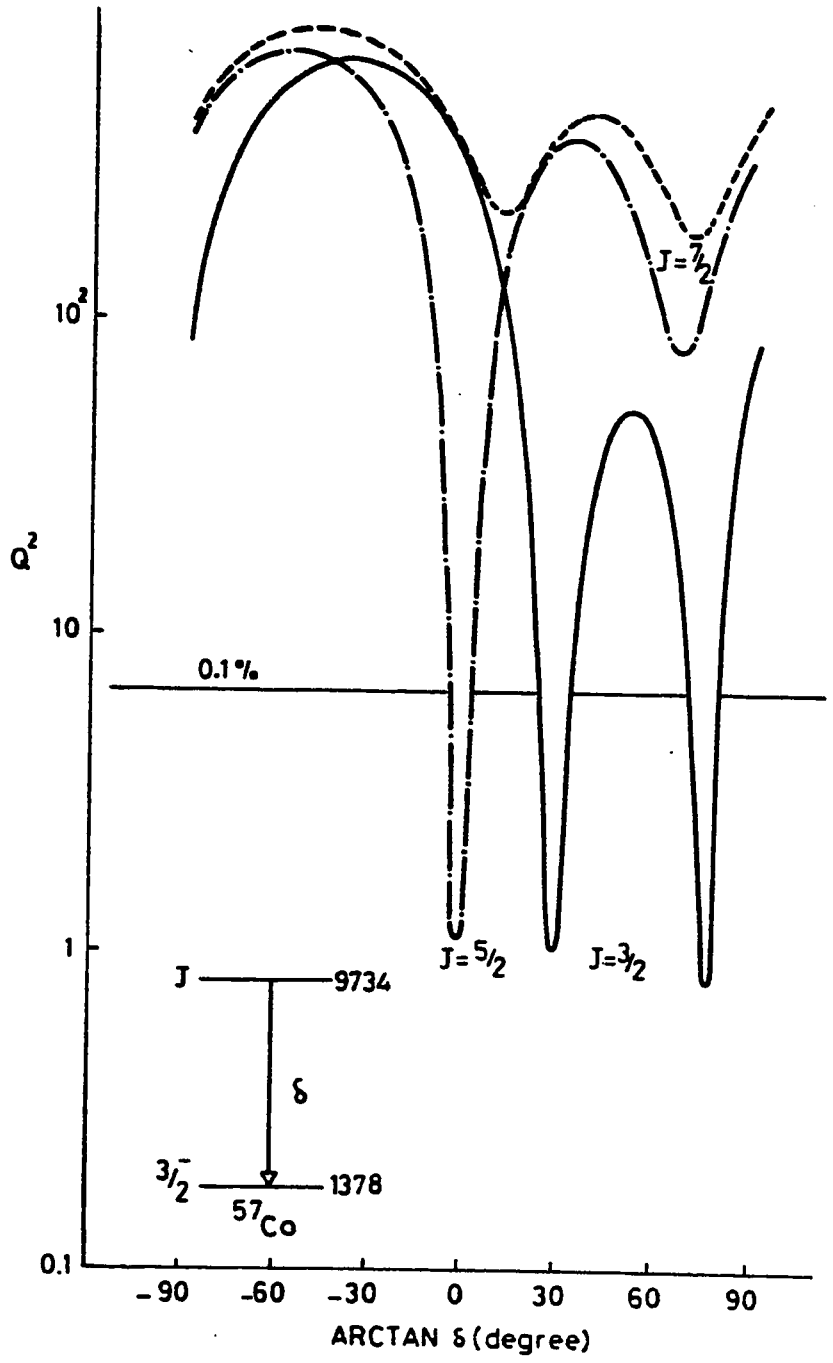


Figure 16: Values of Q^2 versus arctan δ from fitting experimental angular distribution of R to 1378 keV transition to theory for different spin values.

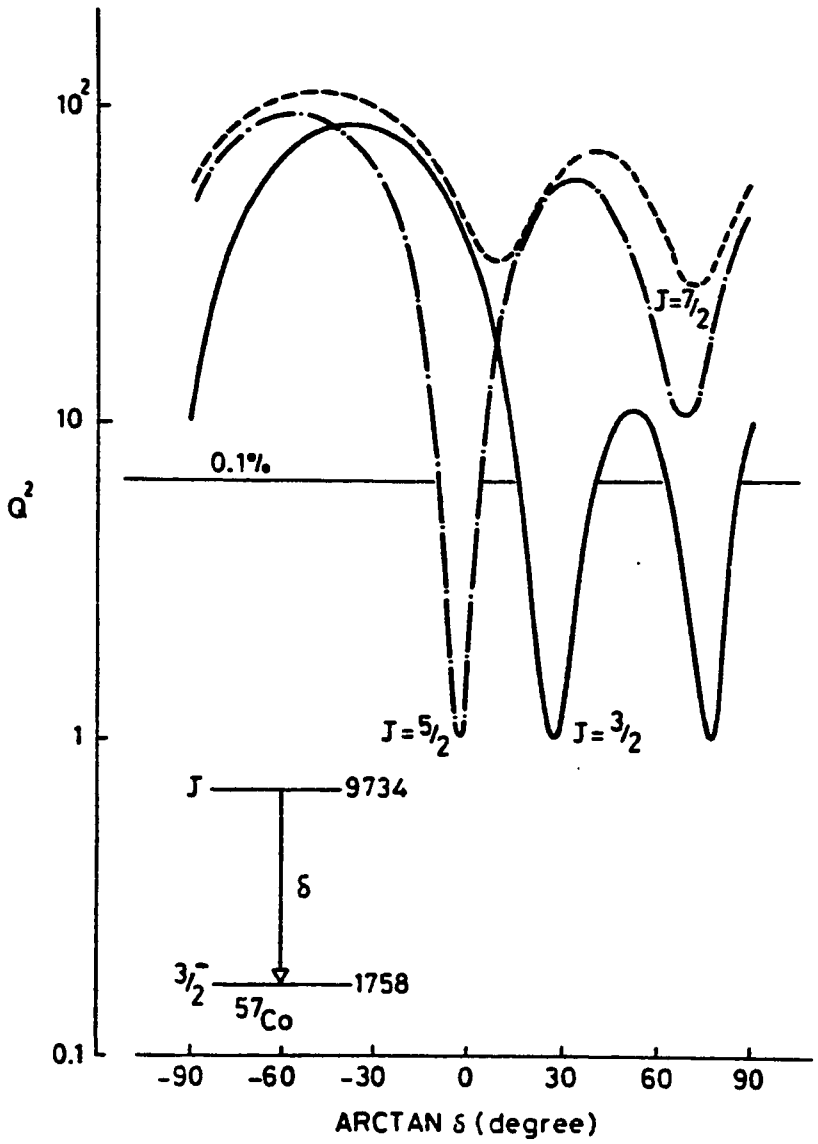


Figure 17 : Values of Q^2 versus arctan δ from fitting experimental angular distribution of R to 1758 keV transition to theory for different spin values.

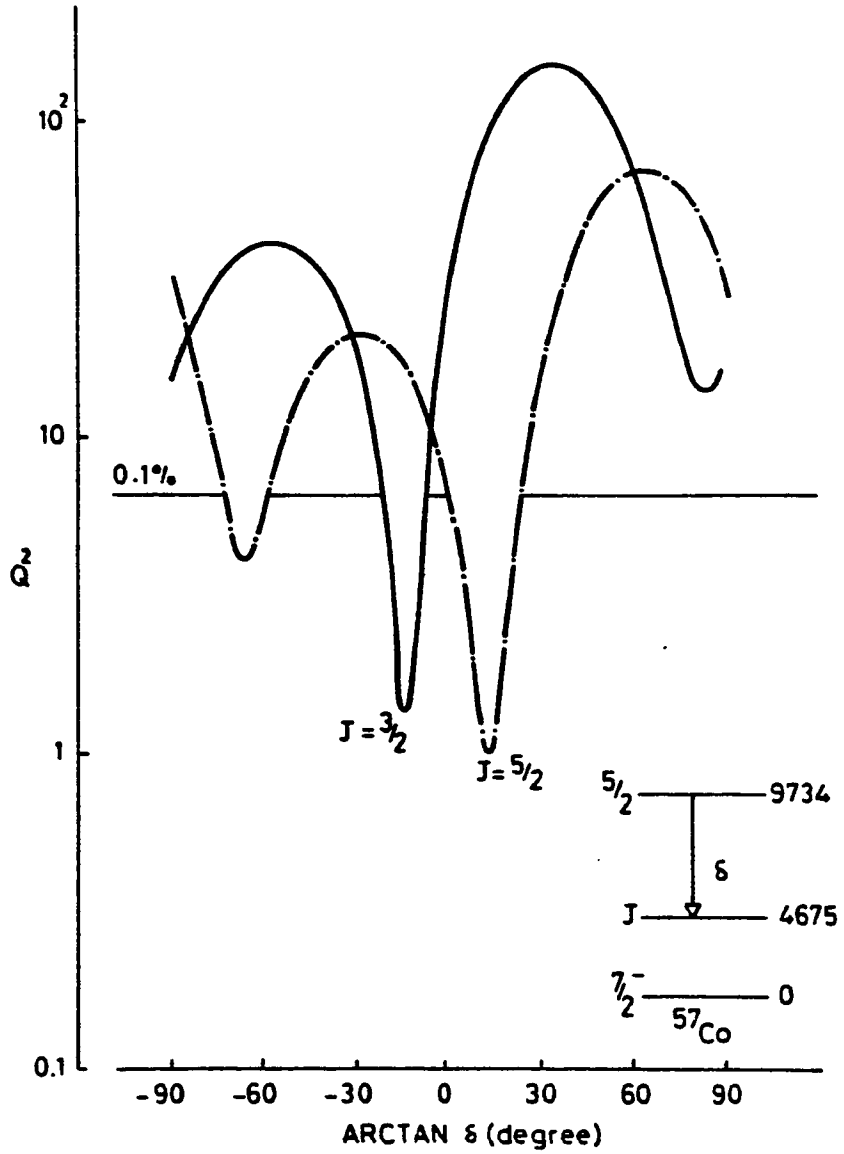


Figure 18 : Values of Q^2 versus arctan δ from fitting experimental angular distribution of R to 4675 transition to theory for different spin values.

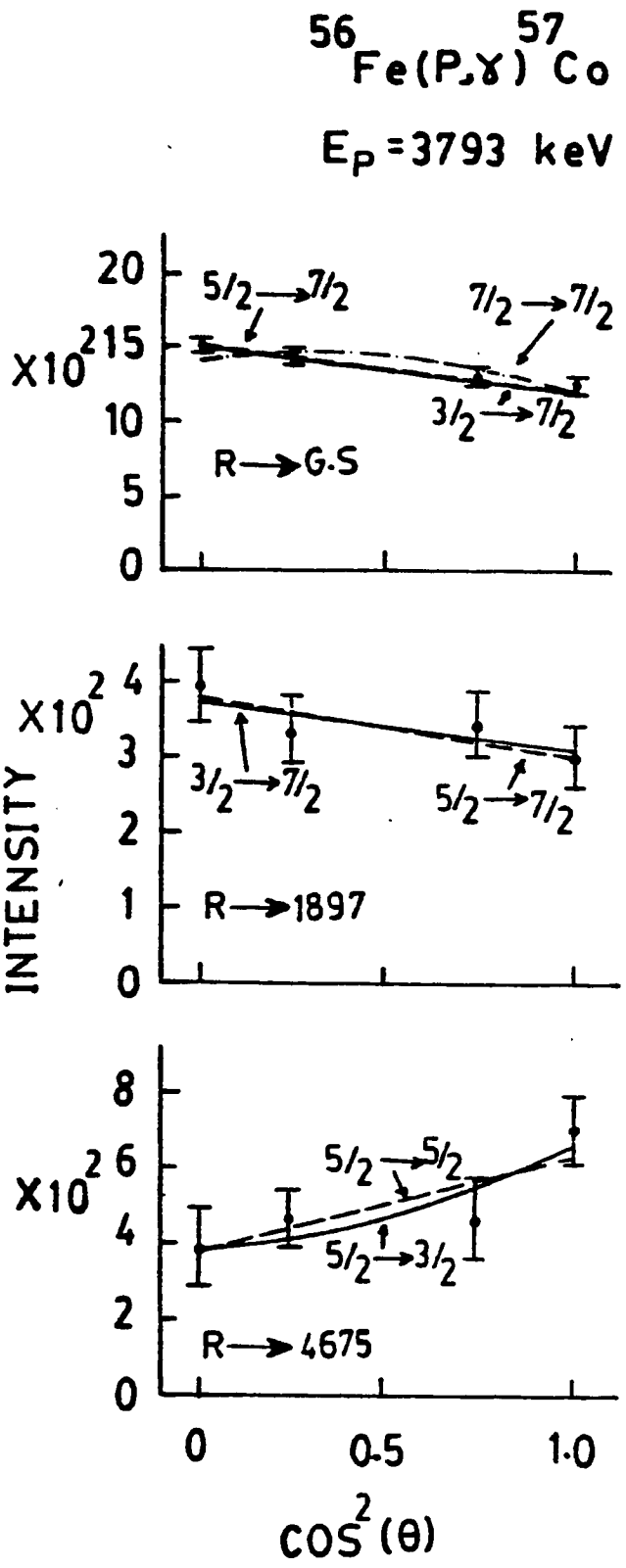


Figure 19 : Experimental angular distribution data and their Least Squares fits for different spin sequences.

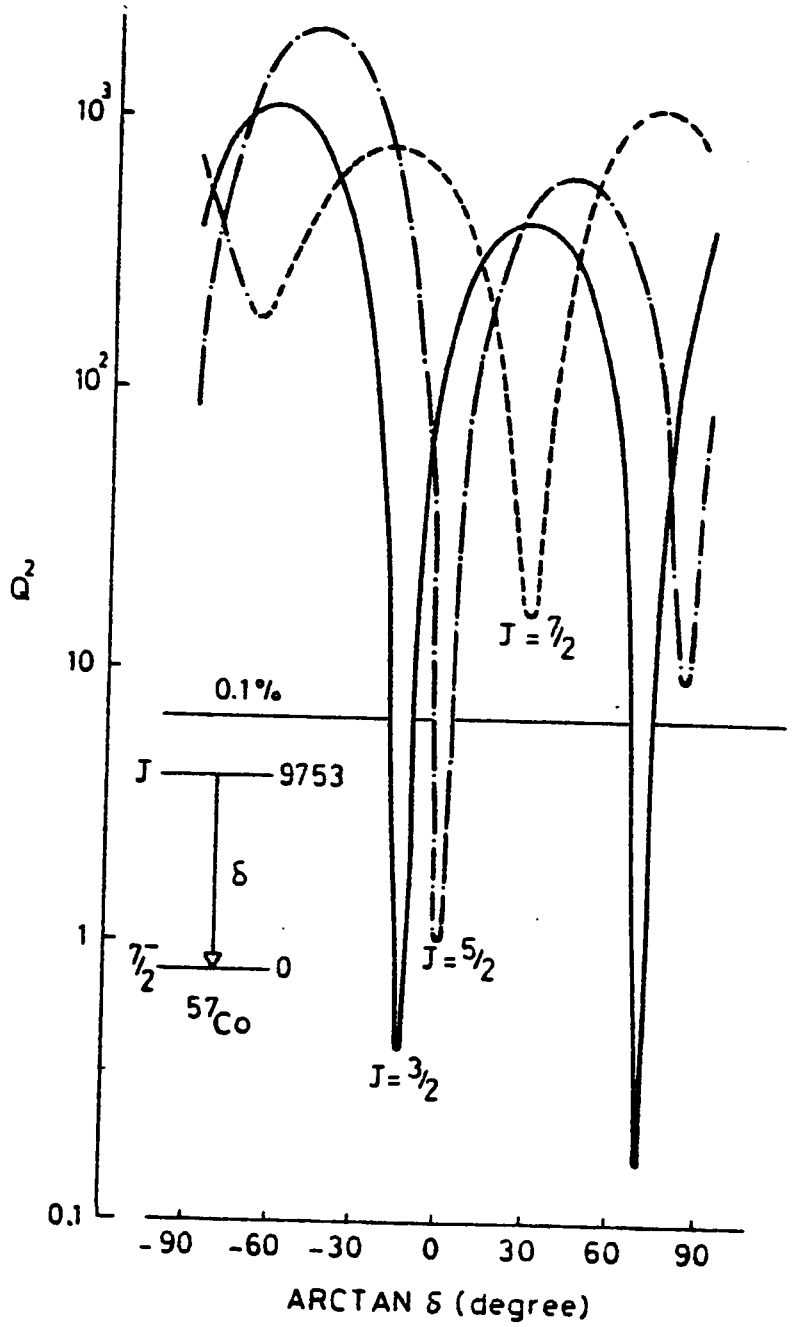


Figure 20 : Values of Q^2 versus arctan δ from fitting experimental angular distribution of R to G.S. transition to theory for different spin values.

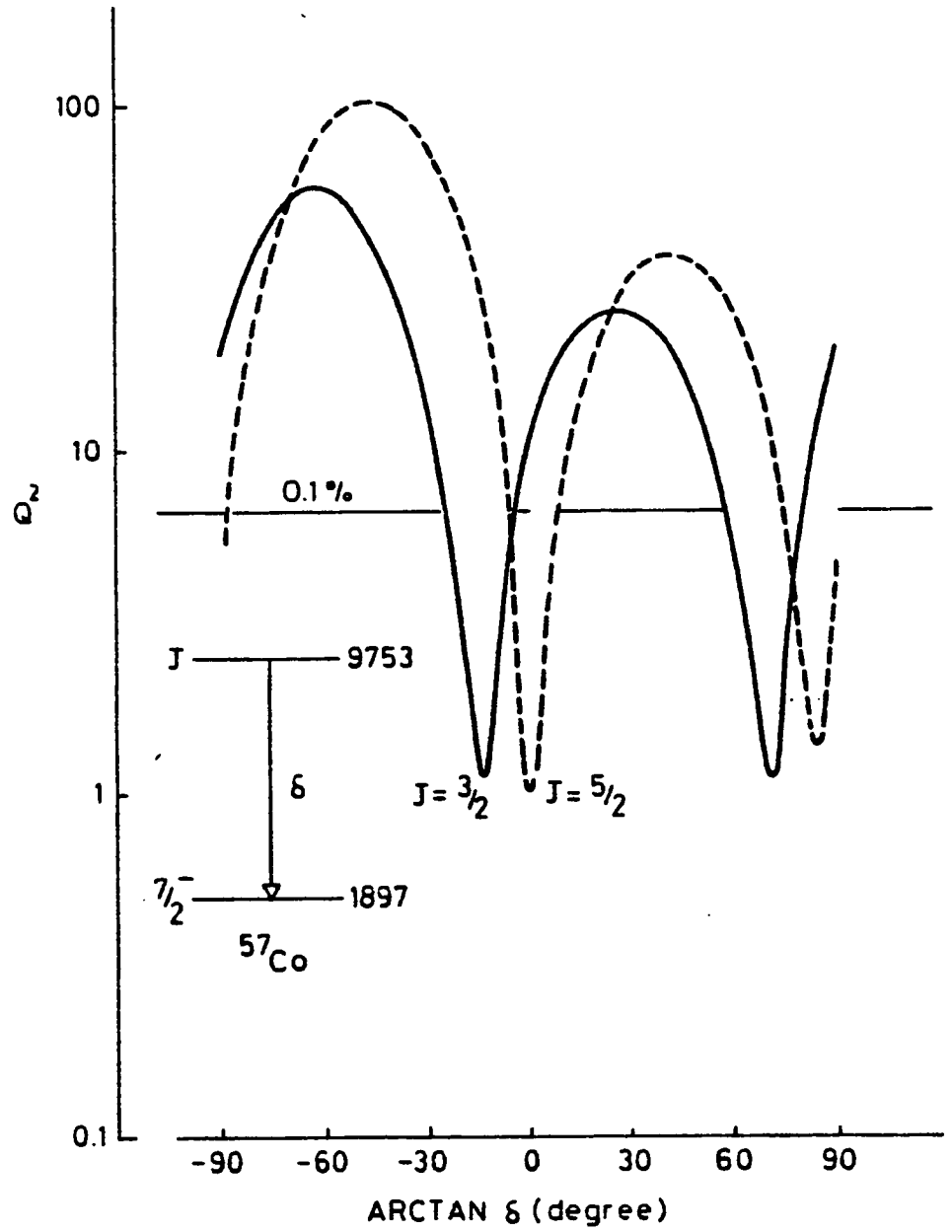


Figure 21 : Values of Q^2 versus arctan δ from fitting experimental angular distribution of R to 1897 keV transition to theory for different spin values.

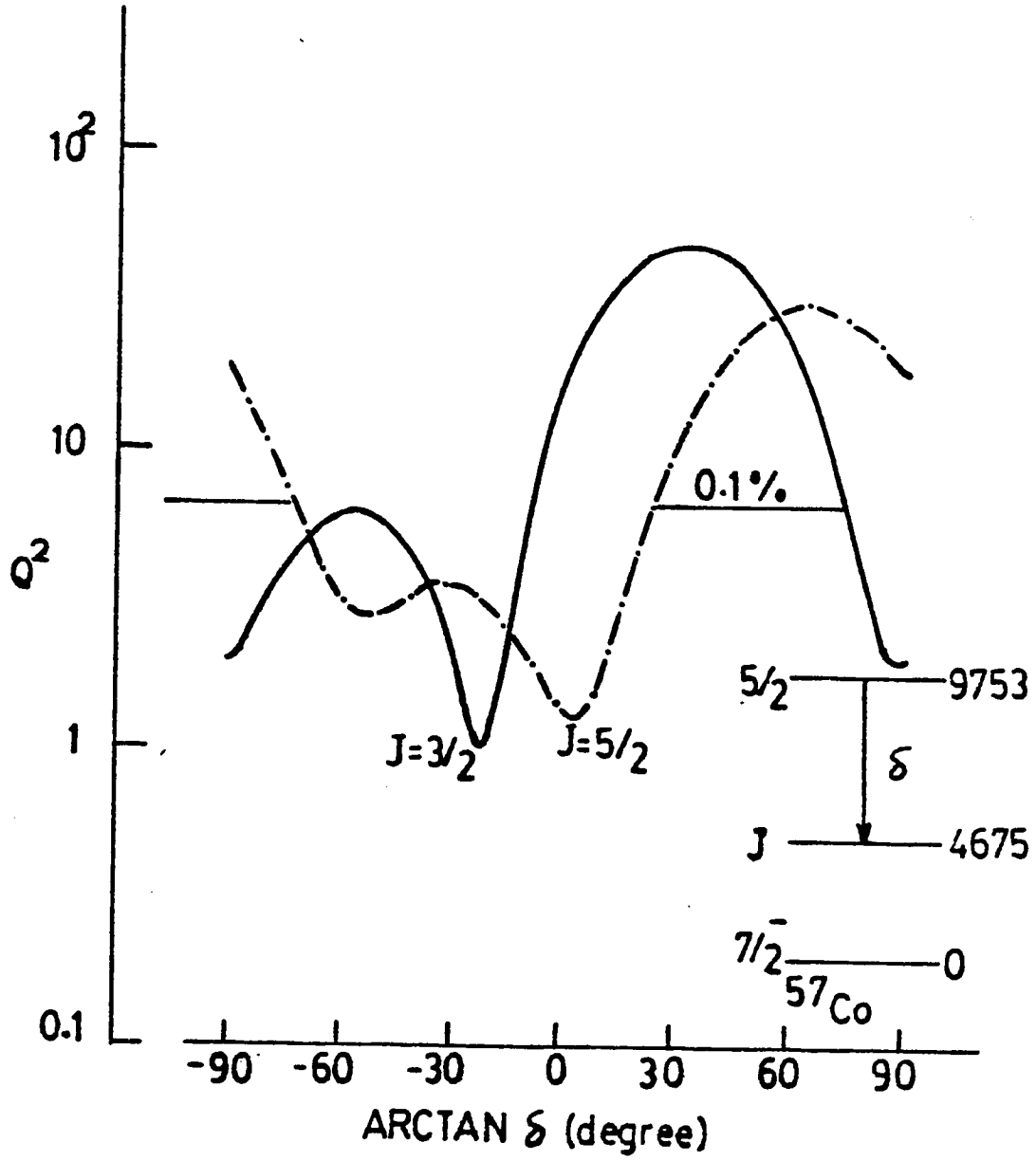


Figure 22 : Values of Q^2 versus arctan δ from fitting experimental angular distribution of R to 4675 keV transition to theory for different spin values.

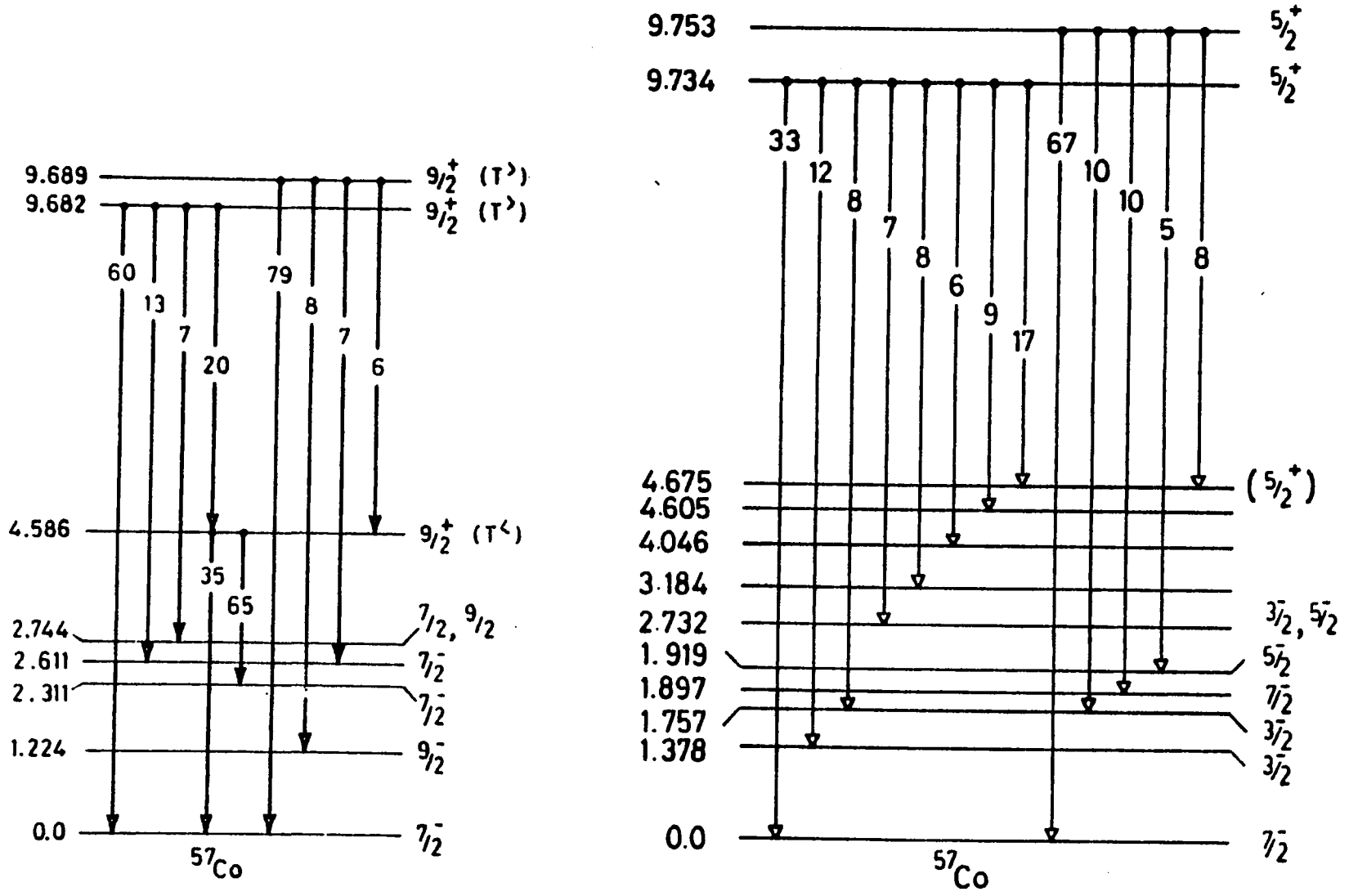


Figure 23 : Decay schemes and spin assignments for E_x=9682, 9689, 9734 and 9753 keV resonant states in ^{57}Co.

TABLE 2 : Comparison Between Branching Ratios of the $g_{9/2}$ IAR as a Result of the Present Study With Those Reported Earlier.

Transition	Resonance at Ep=3720 keV			Resonance at E_p=3727 keV		
	Foder et al. (ref 56)	Rangacharyulu et al.(ref 57)	Present work	Fodor et al. (ref 56)	Rangacharyulu et al.(ref 57)	Present work
R → G.S.	70%	(Strong) No value quoted	60%	74%	70%	79%
R → 1223					15%	8%
R → 1757		(Strong) No value quoted				
R → 2311					15%	
R → 2611	6%		13%	6%		7%
R → 2723	4%			5%		
R → 2744	4%		7%	4%		
R → 4586	16%		20%	11%		6%

TABLE 3 : Experimental Mixing Ratios δ Compared with Weisskopf Values for the Transitions Studied at the E_p=3720 keV Resonance.

Transition $E_i \rightarrow E_f$ (keV)	$J_i \rightarrow J_f^\pi$	Character	Weisskopf Estimate for $\lvert\delta\rvert$	Experimental Mixing Ratios δ	Assigned J^π
9682 → G.S.	$5/2^+ \rightarrow 7/2^-$	E1(M2)	0.0045	-0.176±0.011	
	$5/2^- \rightarrow 7/2^-$	M1(E2)	0.2190	-0.176±0.011	
	$9/2^+ \rightarrow 7/2^-$	E1(M2)	0.0045	0.035±0.011	$J_i^\pi = 9/2^+$
	$9/2^- \rightarrow 7/2^-$	M1(E2)	0.2190	0.035±0.011	
9682 → 4586	$9/2^+ \rightarrow 9/2^-$	E1(M2)	0.0024	0.035±0.020	
	$9/2^+ \rightarrow 9/2^+$	M1(E2)	0.11	0.035±0.020	$J_f^\pi = 9/2^+$
9682 → 2611	$9/2^+ \rightarrow 7/2^-$	E1(M2)	0.0033	0.035±0.013	$J_f^\pi = 7/2^-$
	$9/2^+ \rightarrow 7/2^+$	M1(E2)	0.1600	0.035±0.013	

TABLE 4 : Experimental Mixing Ratios δ Compared with Weisskopf Values for the transitions studied at the E_p=3774 keV Resonance.

Transition $E_i \rightarrow E_f$ (keV)	$J_i \rightarrow J_f^\pi$	Character	Weisskopf Estimate for $\lvert\delta\rvert$	Experimental Mixing Ratios δ	Assigned J^π
9734 → G.S.	$5/2^- \rightarrow 7/2^-$	M1(E2)	0.2202	0.0 ± 0.01	
	$5/2^+ \rightarrow 7/2^-$	E1(M2)	0.0046	0.0 ± 0.01	$J_i^\pi = 5/2^+$
	$3/2^- \rightarrow 7/2^-$	E2(M3)	0.0036	-0.287±0.006	
	$3/2^+ \rightarrow 7/2^-$	M2(E3)	0.1785	-0.287±0.006	
9734 → 1378	$5/2^- \rightarrow 3/2$	M1(E2)	0.1890	-0.035±0.035	
	$5/2^+ \rightarrow 3/2^-$	E1(M2)	0.0039	-0.035±0.035	$J_i^\pi = 5/2^+$
	$3/2^- \rightarrow 3/2^-$	M1(E2)	0.1890	$0.53 \pm \begin{smallmatrix}0.03\\0.01\end{smallmatrix}$	
	$3/2^+ \rightarrow 3/2^-$	E1(M2)	0.0039	$0.53 \pm \begin{smallmatrix}0.03\\0.01\end{smallmatrix}$	

Continued...

TABLE 4 (continued)

Transition $E_i \rightarrow E_f$ (keV)	$J_i \rightarrow J_f^\pi$	Character	Weisskopf Estimate for $\lvert\delta\rvert$	Experimental Mixing Ratios δ	Assigned J^π
9734 → 1757	$5/2^- \rightarrow 3/2^-$	M1(E2)	0.1805	-0.035 ± 0.035	
	$5/2^+ \rightarrow 3/2^-$	E1(M2)	0.0037	-0.035 ± 0.035	$J_i^\pi = 5/2^+$
	$3/2^- \rightarrow 3/2^-$	M1(E2)	0.1805	$0.53 \pm {0.035 \atop 0.07}$	
	$3/2^+ \rightarrow 3/2^-$	E1(M2)	0.0037	$0.53 \pm {0.035 \atop 0.07}$	
9734 → 4675	$5/2^+ \rightarrow 5/2^-$	E1(M2)	0.0024	$0.070 \pm {.07 \atop .11}$	
	$5/2^+ \rightarrow 5/2^+$	M1(E2)	0.1145	$0.070 \pm {.07 \atop .11}$	$J_f^\pi = 5/2^+$
	$5/2^+ \rightarrow 3/2^-$	E1(M2)	0.0024	$-0.404 \pm .05$	
	$5/2^+ \rightarrow 3/2^+$	M1(E2)	0.1145	$-0.404 \pm .05$	

TABLE 5 : Experimental Mixing Ratios δ Compared with Weisskopf Values for the Transitions Studied at the E_p = 3793 keV Resonance.

Transition $E_i \rightarrow E_f$ (keV)	$J_i \rightarrow J_f^\pi$	Character	Weisskopf Estimate for $\lvert\delta\rvert$	Experimental Mixing Ratios δ	Assigned J^π
9753 → G.S.	$5/2^- \rightarrow 7/2^-$	M1(E2)	0.2207	0.0±.03	
	$5/2^+ \rightarrow 7/2^-$	E1(M2)	0.0046	0.0±.03	$J_i^\pi = 5/2^+$
	$3/2^+ \rightarrow 7/2^-$	M1(E2)	0.2207	-0.249 ± .017	$= 3/2^+$
	$3/2^+ \rightarrow 7/2^+$	E1(M2)	0.0046	-0.249 ± 0.017	
9753 → 1897	$5/2^- \rightarrow 7/2^-$	M1(E2)	0.1777	0.0 ± .035	
	$5/2^+ \rightarrow 7/2^-$	E1(M2)	0.0037	0.0 ± .035	$J_i^\pi = 5/2^+$
	$3/2^- \rightarrow 7/2^-$	E2(M3)	0.0029	-0.249 ± .035	
	$3/2^+ \rightarrow 7/2^-$	M2(E3)	0.1441	-0.249 ± .035	
9753 → 4675	$5/2^+ \rightarrow 3/2^-$	E1(M2)	0.0024	-0.404 ± 0.05	
	$5/2^+ \rightarrow 3/2^+$	M1(E2)	0.1149	-0.404 ± 0.05	
	$5/2^+ \rightarrow 5/2^-$	E1(M2)	0.0024	$-0.0699 \pm \begin{matrix}.09\\.12\end{matrix}$	
	$5/2^+ \rightarrow 5/2^+$	M1(E2)	0.1149	$0.0699 \pm \begin{matrix}.09\\.12\end{matrix}$	$J_f^\pi = 5/2^+$

TABLE 6 : Comparison of the Resonances Studied in the Present Work with those expected for Analogues of States of ^{57}Fe.

Parent States in ^{57}Fe		Expected Analogue States in ^{57}Co			Observed Analogue States in ^{57}Co		
E^* (keV)	J^π	E_x (keV)	E_p (keV)	J^π	E_x (keV)	E_p (keV)	J^π
2455	$9/2^+$	9712	3707	$9/2^+$	9682 9689	3720 3727	$9/2^+$ $9/2^+$
2506	$5/2^+$	9763	3758	$5/2^+$	9734 9753	3774 3793	$5/2^+$ $5/2^+$

APPENDIX "A"

ANGULAR CORRELATION FORMALISM

Many books and review articles have been published discussing the formalism of angular correlation (67-71).

In the factored formalism, the notation used follows closely the notation of Smith (68,69). The angular distribution data presented in the present work on $^{56}Fe(p,\gamma)^{57}Co$ were analyzed using this factored formalism. For a two step gamma-ray cascade (Figure 24), the angular correlation function specifying the relative intensity $W(\theta_1,\theta_2,\phi)$ can be written as:

$$W(\theta_1,\theta_2,\phi) = \sum_{KMN} A^N_{KM} Q_K Q_M X^N_{KM}(\theta_1,\theta_2,\phi) \quad (1)$$

where θ_1 and θ_2 are the angles between the propagation vectors of the incoming beam and of the primary and secondary radiation and ϕ is the relative azimuthal angle between them. The Q_K and Q_M are finite geometry detector correction factors. The functions $X^N_{KM}(\theta_1,\theta_2,\phi)$ are the angular functions and defined as:

$$X^N_{KM}=[(2M+1)(2K+1)(K-N)!(M-N)!/(K+N)!(M+N)!]^{1/2}P^N_K(\cos\theta_1)$$

$$P^N_M(\cos\theta_2)\ \cos N\phi \quad (2)$$

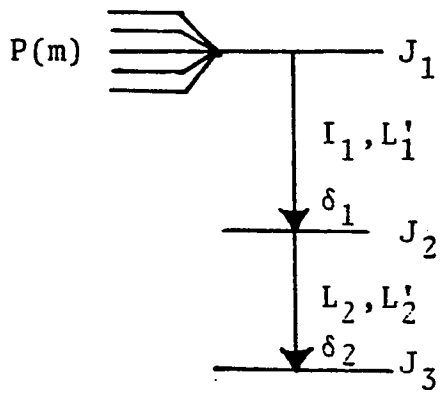


Figure 24 : Schematic energy level diagram to illustrate the quantum numbers used for a double gamma-ray cascade from an aligned nuclear state.

Under the conditions of defined parities and sharp spin of all levels, and of unpolarized bombarding particles and target, K and M can take on even integral values, K takes all even integral values up to the order of the highest multipolarity occuring in the primary transition of the cascade, i.e. $|L_1-L_1'| \leq K \leq L_1+L_1'$. M is limited by either the multipolarity of the second member of the cascade of the spin J_2 of the intermediate level, whichever is smaller, i.e. $M \leq \text{min.}\ (L'_2+L_2', J_2+J_2')$. N may take any positive value from zero to the smallest of K and M. $P_K^N(\cos\theta_1)$ and $P_M^N(\cos\theta_2)$ are the associated Legendre polynomials, where the associated Legendre polynomials, can each be expressed as a sum of the ordinary Legendre polynomials as:

$$P^N{}_V(\cos\theta) = \sum_k P^N{}_{VK}\ P_k\ (\cos\theta)$$

where V=K or M and k is even and does not exceed K or M.

The expansion coefficient A^N_{KM}, characterizes a certain spin sequence, e.g. $J_1 \rightarrow J_2 \rightarrow J_3$. In the population parameter representation this coefficient is given by:

$$A^N_{KM} = \sum_{m \geq 0} P(m) \overline{\sum_{L_1 L_1' L_2 L_2'}} \delta_1^{P_1} \delta_2^{P_2} C^N_{KM} \qquad (3)$$

where

$$C^N_{KM} = \beta (-)^f (2J_1+1)(2J_2+1)(2L_1+1)^{\frac{1}{2}} (2L_1'+1)^{\frac{1}{2}} (2L_2+1)^{\frac{1}{2}}$$

$$(2L_2'+1)^{\frac{1}{2}} \langle L_1\ 1\ L_1'-1 \mid KO\rangle \langle L_2\ 1\ L_2'-1 \mid MO\rangle W(J_2 L_2 J_2 L_2'; J_3$$

$$M) \sum_k (-1)^{J_1 - m} \langle J_1 m J_1 -m \mid KO\rangle \langle K-N\ M\ N \mid KO\rangle F(L_1')$$

where

$$F(S) = \begin{vmatrix} J_2 & L_1 & J_1 \\ J_2 & S & J_1 \\ M & K & k \end{vmatrix} \qquad (4)$$

where $(-)^f$ is a phase factor where $f = J_3-J_3-J_2+L'_1-L_2+L'_2+M+N$ and β is a multiplicity term where $\beta = (2-\delta_{N,0})(2-\delta_{L_1,L'_1})(2-\delta_{L_2,L'_2})$. In the A^N_{KM} expansion given by equation (3), P_1 and P_2 take on the values 0, 1 or 2 for pure L, mixed L,L' or pure L' radiation. The quantities δ_1 and δ_2 are the ratios of reduced matrix elements for L'-pole to L-pole radiation, i.e. $\delta_1=\langle J_2|L'|J_1\rangle/\langle J_2|L|J_1\rangle$. $P_{(m)}$ is the population parameter of the substates +m plus that of substate -m. The δ in the β multiplicity term is the Kronecker delta. The C^N_{KM} and h_M coefficients, thus

$$C^N_{KM}(J_1J_2J_3L_1L'_1L_2L'_2m)=E^N_{KM}(J_1J_2L_1L'_1m)\quad h_M(J_2J_3L_2L'_2)$$

where

$$E^N_{KM}=(-)^{L'_1+N+1}(2-\delta_{N,0})(2-\delta_{L_1,L'_1})(2J_1+1)(2J_2+$$

$$1)^{\frac{1}{2}}(2L+1)^{\frac{1}{2}}(2L'+1)^{\frac{1}{2}}\langle L_1\ 1\ L'_1\ -1|KO\rangle\ \sum_K\ (-)^{J_1-m}\langle\ J_1$$

$$-m|KO\rangle\ \langle K-N\ M\ N|KO\rangle\ F(J'_1) \qquad (5)$$

and

$$h_M(J_2J_3L_2L'_2)=(2J+1)^{-\frac{1}{2}}(-)^{J_3-J_2}(2-\delta_{L_2,L'_2})\quad \bar{Z}_1(L_2J_2L'_2J_2;J_3M) \qquad (6)$$

Expression (5) for E^N_{KM} depends only on parameters of the primary radiation while expression (6) for h_M depends only on parameters of the secondary radiation. One can write expression (3) as:

$$A^N_{KM} = \sum_m P(m) \sum_{L_1,L_1'} \frac{\delta_1^{P_1}}{(1+\delta_1^2)} E^N_{KM}(J_1 J_2 L_1 L_1' m) \times$$

$$\sum_{L_2,L_2'} (\delta_2^{P_2}/(1+\delta_2^2)) h_M(J_2 J_3 L_2 L_2') \qquad (7)$$

From expressions (1) and (7) one can introduce two quantities:

$$G_{mM}(\delta_1,\theta_1,\theta_2,\phi) = \sum_{L_1,L_1'} (\delta_1^{P_1}/(1+\delta_1^2)) \sum_{KN} E^N_{KM}(J_1\ J_2\ L_1\ L_1'\ m)$$

$$Q_K\ Q_M\ X^N_{KM}(\theta_1,\theta_2,\phi) \qquad (8)$$

and

$$H_M(J_2\ J_3\ \delta_2) = \sum_{L_2,L_2'} (\delta_2^{P_2}/(1+\delta_2^2))\ h_M(J_2\ J_3\ L_2\ L_2') \qquad (9)$$

Thus one can write the triple correlation function in terms of the two parameters G_{mM} and H_M, thus:

$$W(\theta_1,\theta_2,\phi) = \sum_{nM} P(m)\ G_{mM}(\delta_1,\theta_1,\theta_2,\phi)\ H_M(\delta_2) \qquad (10)$$

where

$$H_M(\delta_2)=[h_M(J_2\ L_2\ L_2 J_3)+\delta_2\ h_M(J_2\ L_2\ L_2'\ J_3)+\ \delta_2{}^2\ h_M(J_2'\ L_2'\ J_3)]\ /(1+\delta_2{}^2)$$

The angular distribution of the primary gamma-ray is obtained by averaging the triple correlation formula over all directions of the secondary gamma-ray, i.e. over θ_2 and ϕ. When this is done all terms for which $M\neq 0$ vanish, this provides:

$$W(\theta_1) = \sum_m P_m(J_1)\ G_{mM}\ (\delta_1,\theta_1)$$

$$= \sum_m P_m(J_1) \sum_{L_1,L_1'} \sum_K (2K+1)^{\frac{1}{2}}\ \frac{\delta_1^{P_1}}{1+\delta_1^2}\ E^O_{KO}(J_1 L_1 L_1' J_2 m)$$

$$x\ Q_K\ X^O_{KO}\ (\theta_1) \qquad (11)$$

APPENDIX "B"

SELECTION RULES FOR GAMMA RAY TRANSITIONS AND UNITS OF TRANSITION STRENGTHS

The particle capture by an atomic nucleus results in an excited state with an excitation energy more than the particle binding energy in the compound system. The formed state can decay in different ways governed by energetics and selection rules. Gamma-ray emission can compete with particle emission because it is usually exoergic, the amount of energy available being of the order of several MeV. As a consequence, radiative capture will be the dominant process when resonances occur for sufficiently low energies of the incident particle and when there are no competing exoergic reactions. When the incident particle is charged the widths for reemission are tremendously reduced by a coulomb barrier, so that radiative capture can be the dominant compound nuclear process over a considerable range in energy. However, if neutron emission (e.g. a (p,n) reaction) is possible it will generally be more probable than gamma-ray emission.

The probability of particle emission (72) is proportional to V/R, where V is the velocity of the particle and R is the nuclear dimension, while for gamma-

ray emission this probability is proportional to $e^2/\hbar C.(V/C)^2$. V/R which is very small since V/C < 1 and e^2/hC is very small.

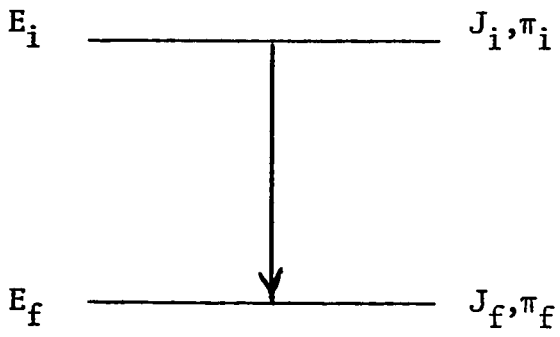


Figure 25 : Symbols for a gamma-ray transition.

B-1 Selection Rules

The general selection rules for an electromagnetic transition between an initial state of energy E_i, spin J_i and parity π_i and a final state E_f, spin J_f and parity π_f are summarized in the above Figure 25.

A) The energy of the emitted gamma-ray is given by:

$$E_\gamma = (E_i - E_f)/(1+E_\gamma/2MC^2)$$

where $E_\gamma/2MC^2$ is the energy of the recoil nucleus and

is very small, hence $E_\gamma \sim E_i - E_f$.

B) The angular momentum carried by the gamma quantum can have any of the values

$$|J_i - J_f| \leq L \leq J_i + J_f$$

C) If J_i or $J_f = 0$; then only electric or only magnetic radiations could be emitted without any mixing.

D) If $J_i = J_f = 0$; then the transition between these two sites by only one gamma quantum is forbidden. The transition between such states can go by means of a single electron (internal conversion) or through a pair emission if $E_i - E_f > 2m_0C^2$, these two processes can take place if parity does not change. If parity changes, then, this transition can occur by means of two internal conversion electrons or one internal conversion electron and one gamma quantum.

E) The parity change between these two states as a result of gamma-ray emission is determined not only by the multipolarity L but also by the character of the transition whether electric or magnetic. The parity changes as $(-)^L$ for electric transitions and as $(-)^{L+1}$ for magnetic transitions. Table (7) lists multi-polarities to be expected for a gamma-transition between

two states of specified angular momenta and parities.

TABLE 7

POSSIBLE MULTIPOLARITIES FOR GAMMA TRANSITION

Parity Change $\Delta\pi$	Change of Angular Momentum $\lvert J_i - J_f \rvert$				
	0 or 1	2	3	4	5
No	M1(E2)	E2(M3)	M3(E4)	E4(M5)	M5(E6)
Yes	E1(M2)	M2(E3)	E3(M4)	M4(E5)	E5(M6)

Three further isospin selection rules are obtained when T is a good quantum number, viz.

(i) all gamma-transitions are forbidden when $|\Delta T| > 1$

(ii) E1 gamma-transitions are forbidden between two states in a self-conjugate nucleus (i.e., one with N=Z) when $\Delta T=0$.

(iii) There may be an inhibitory effect on other multiples (e.g. on M2) when $\Delta T=0$.

Gamma-rays of different multipole orders and different characters can compete with each other in radiative transitions. The relative contribution of L+1 to L radiations (e.g. M2 to E1 or E2 to M1) is defined by Moskowski (73) as δ^2 and given by:

$$\delta^2 = \frac{\text{Intensity of radiation L+1}}{\text{Intensity of radiation L}} = \left[\frac{\langle J_f | L+1 | J_i \rangle}{\langle J_f | L | J_i \rangle}\right]^2$$

and definition of δ is taken to be $= \frac{\langle J_f \ L+1 \ J_i \rangle}{\langle J_f \ L \ J_i \rangle}$

The mixing ratio δ is real and can be either positive or negative depending on whether the two radiations are in phase or antiphase respectively. These relative contributions could be calculated according to the theory of electromagnetic transitions. The probability of transition by an electric radiation of multipolarity is given by:

$$T_E(L) = \frac{2\pi(L+1)}{L[(2L+1)!!]^2} \cdot \frac{K^{2L+1}}{\hbar} |Q_L|^2$$

The transition probability by a magnetic radiation of multipolarity L is given by:

$$T_M(L) = \frac{2\pi(L+1)}{L[(2L+1)!!]^2} \cdot \frac{K^{2L+1}}{\hbar} |M_L|^2$$

where $(2L+1)!! = 1 \times 3 \times 5 \ldots\ 2L+1 = \frac{(2L+1)!}{2^L \times L!}$,

$K = \frac{1}{\lambda}$ = wave number of the gamma radiation,

Q_L , Q_M = electric and magnetic transitions when transforming from one state to another. The values of Q_L and M_L are proportional to the nuclear dimension as:

$$Q_L \sim R^L \quad \text{and} \quad M_L \sim V/C \cdot R^L$$

Hence:

$$T_E(L) \sim (R/\lambda)^{2L} \text{ and}$$

$$T_M(L) \sim (V/C)^2 (R/\lambda)^{2L}$$

Thus, the relative contributions of different radiations could be roughly estimated as:

$$T_M(L)/T_E(L) \sim (V/C)^2 \sim 10^{-2}$$

$$T_E(L)/T_E(L+1) \sim (R/\ )^{-2} \sim 10^{-4}$$

$$T_M(L)/T_E(L+1) \sim (V/C)^2/(R/\lambda)^2 \sim 10^2$$

$$T_E(L)/T_M(L+1) \sim (R/\lambda)^{2L}/(V/C)^2 (R/\lambda)^{2L+2} \sim 10^6$$

$$T_E(L)/T_E(L+2) \sim (R/\lambda)^{2L}/(R/\lambda)^{2L+4} \sim 10^8$$

In the above calculations $V^2 = \frac{2E}{M} = 16 \times 10^{18}$ cm^2/sec^2, (E = kinetic energy of a nucleon of mass M in the nucleus and is of the order of the binding energy of the nucleon $\sim$ 8 MeV), $C = 3 \times 10^{10}$ cm/sec, $R = r_o A^{1/3} \sim 1.3 \times 10^{-13}$ cm and $\lambda = \frac{Ch}{E} \approx 2 \times 10^{-11}$ cm for a gamma-ray of energy 1 MeV. From these considerations we may arrive at the conclusion that in the analysis of experimental data we may neglect the contribution of higher order multipoles, e.g. we can neglect the contribution of M3 to E2 radiations.

B-2 Units of Transition Strengths

The transition probability of an excited nuclear state for gamma-radiation depends on the multipolarity, the energy of the gamma-ray and the wave functions of the nuclear states involved in the transition. Due to this dependence, significant information regarding nuclear wave functions can be obtained from a comparison of experimental gamma-decay transition probabilities with theoretical values (see reference 72) calculated on the basis of specific models of the nucleus. Hence, the most useful way to express the transition strength is in terms of a transition of the same energy and type calculated according to a certain model for a nucleus of the same size. The model most generally used is the extreme single particle model.

The results given for the strengths of radiative transitions for both electric 2^L-pole and magnetic 2^L-pole are measured in Weisskopf units.

For electric transitions if we measure "E_γ" in MeV and R in fermis we have:

$$\tau_\gamma^{-1}(EL) = \frac{4.4(L+1)}{L[(2L+1)!!]^2} \cdot \left[\frac{3}{L+3}\right]^2 \cdot \left[\frac{E_\gamma}{197}\right]^{2L+1} xR^{2L}x10^{21}\ sec^{-1}$$

where $R = r_o A^{1/3}$ and $r_o = 1.20$ fermis. Then the radiative widths "Γ_γ" in ev for electric transitions are given in Weisskopf units as:

$$\Gamma_{\gamma W}(E1) = 6.8 \times 10^{-2}\ A^{2/3}E_\gamma^3 \quad ev\ ;$$

$$\Gamma_{\gamma W}(E2) = 4.9 \times 10^{-8}\ A^{4/3}E_\gamma^5 \quad ev\ ;$$

$$\Gamma_{\gamma W}(E3) = 2.3 \times 10^{-14}\ A^2E_\gamma^7 \quad ev\ .$$

For magnetic transitions the calculation of the Weisskopf units are difficult because of the complication of the intrinsic magnetic moments of the nucleus. As was mentioned before, the magnetic matrix elements is smaller than the electric matrix element by a factor of the order V/C. This factor amounts to $\hbar/MCR$ (see reference 72) where

"M" is the nucleon mass. Then the squares of the matrix elements for magnetic and electric transitions could be related by $10(\hbar/MCR)^2$, which leads to:

$$\tau_\gamma^{-1}(ML) = \frac{1.9(L+1)}{L[(2L+1)!!]^2} \cdot \left(\frac{3}{L+3}\right)^2 \left(\frac{E_\gamma}{197}\right)^{2L+1} \times R^{2L-2} \times 10^{21} \text{sec}^{-1}$$

and the Weisskopf estimates are:

$$\Gamma_{\gamma W}(M1) = 2.1 \times 10^{-2} \; E_\gamma^3 \quad \text{ev} \; ;$$

$$\Gamma_{\gamma W}(M2) = 1.5 \times 10^{-8} \; A^{2/3} \; E_\gamma^5 \; \text{ev} \; ;$$

$$\Gamma_{\gamma W}(M3) = 6.8 \times 10^{-15} \; A^{4/3} \; E_\gamma^7 \quad \text{ev} \; .$$

APPENDIX "C"

GAMMA-RAY ANALYSIS PROGRAM

```
C
      LOGICAL*1 STAR(4100,80),ST
      DOUBLE PRECISION ACC(4100),ACCUM
      CHARACTER*2 PQ(260),SQ(5),AQ(260),FQ(300)
      CHARACTER*4 FIL,REC,EFFCOR
      CHARACTER*1 DOT(101)
      CHARACTER*8 SPIN(160)
      DIMENSION CO(4100),E(4100)
      REAL SLOPE,Y,A(128,2),ESET(2),X(4100,2),DL(10),
     *LB,FEP(48),DEP(48),EM(48,3),CPK(260),UCPK(260),UPERC(260),
     *PPE(260),DSE(260),EFSH(260),FULL(260),LEV(260),LLEVEL(260),
     *FLEVEL(300),FCNTRD(300),FNTRD(300),FP(300),FRP(300),FPB(300),
     *FUB(300),FPNET(300),FUPNET(300)
      INTEGER CH(4100),MULTIP(4100),A1,A2,A3,A4,A5,A6,CSET(2),
     *SC,RUN,Q(260),CAL,RITE,F(300)
     *AT1,AT2,X1(260),X2(260),X3(260),X4(260),X5(260),X6(260),
     *FX1(260),FX2(260),FX3(260),FX4(260),FX5(260),FX6(260)
      DIMENSION   ECNTRD(260),CNTRD(260),RP(260),T(50,2),
     *URP(260),PB(260),PNET(260),UPNET(260),UB(260)
C.....
C.....
C.....
      ISMTH=04
      RUNSET=6
      CALSET=0
      RITE=1
      EFFCOR='NO '
C.....
C.....
C.....
      READ(8,1999)
      IF(RITE.EQ.1)WRITE(9,1999)
1999  FORMAT (' ',/,/,/,/,/)
      READ(8,*)RUN,CAL,FIL,REC,RESON,ERR
      ERR=12.0
      READ(8,*)AA,BB,CC
      RUN=RUNSET
      CAL=CALSET
      IF(RITE.EQ.1)WRITE(9,75175)RUN,CAL,FIL,REC,RESON,ERR
      IF(RITE.EQ.1.AND.CAL.EQ.0)WRITE(9,*)AA,BB,CC
75175 FORMAT(T2,2I6,1H ,1H',A3,1H',1H ,1H',A3,1H',2F8.1)
C$OPTIONS LINES=8400,WARN,NOLIST
      READ(8,1099)
      IF(RITE.EQ.1)WRITE(9,1099)
1099  FORMAT (' ')
C.....
C.....
C.....
      DO 1119 IS=1,101
      DOT(IS)='.'
```

```
1119 CONTINUE
      DATA ST/'*'/
      IF(RUN.LE.2)GO TO 3244
      DATA FEP/0.94, 1.0,  1.05, 1.1,  1.17,1.25, 1.3,  1.38,  1.47,
     *1.52,1.6, 1.7, 1.8,  1.9,  2.,   2.1,  2.22, 2.35 ,2.5  ,2.6 ,
     *2.75, 2.9 , 3.05 ,3.2 ,
     *3.35,3.55,3.7, 3.9 , 4.1 , 4.38, 4.6 , 4.8 , 5.1 , 5.4  ,5.8,
     *6.2, 6.5 ,6.9, 7.3,  7.8 , 8.4 , 8.9 , 9.6 , 10.5 ,11.5, 12.5,
     *13.5,15./
      DATA DEP/  2.25,2.35, 2.45, 2.55, 2.7,  2.8,  2.9 , 3. ,  3.13
     *3.25, 3.37,3.5, 3.6 , 3.7 , 3.8 , 3.9 , 4.,    4.05, 4.12, 4.2,
     *4.3,  4.35,4.4 ,4.405,4.41, 4.42, 4.43, 4.46, 4.48, 4.5 , 4.48
     *4.45 ,4.42,4.4, 4.37, 4.27 ,4.18, 4.03, 3.9 , 3.8 , 3.65 ,3.5,
     *3.3 , 3.1, 2.9 ,2.7 , 2.4 , 2.15/
      EME=12000.
      DO 324 JT=1,48
      JE=48-JT+1
      IF(JE.EQ.0)GO TO 324
      EM(JE,1)=EME
      EM(JE,2)=ALOG(FEP(JT))
      EM(JE,3)=ALOG(DEP(JT))
      EME=EME-200.
324   CONTINUE
C     CALL PLOT(22,EM,48,3,48,0,E,CO,DOT)
C     ..................................................
C     ..................................................
C     ..................................................
C     .DEFINITIONS:                                    .....
C     E=ENERGY
C     CH(X)=CHANNEL # X
C     CO(X)=COUNTS IN CHANNEL # X
C     ACC(X)=TOTAL COUNTS UP TO CHANNEL # X
C     ..................................................
C     ..................................................
C     ..................................................
3244  EXECUTE HEAD
      WRITE(6,66)
      WRITE(6,77)
      N=1
      LOOP
         IF(N.GT.410)QUIT
         READ(8,7766)L$,(DL(I4),I4=1,10)
         ATEND,QUIT
         IF(RITE.EQ.1)WRITE(9,7766)L$,(DL(I4),I4=1,10)
         N1=(N-1)*10
         CO(N1+1)=DL(1)
         CO(N1+2)=DL(2)
         CO(N1+3)=DL(3)
         CO(N1+4)=DL(4)
         CO(N1+5)=DL(5)
         CO(N1+6)=DL(6)
         CO(N1+7)=DL(7)
         CO(N1+8)=DL(8)
         CO(N1+9)=DL(9)
         CO(N1+10)=DL(10)
         IF(RUN.EQ.0)WRITE(6,*)N1
         IF(RUN.EQ.0)WRITE(6,1002)L$,(CO(N1+I),I=1,10)
         N=N+1
      ENDLOOP
C     ..................................................
```

```
11221 CONTINUE
   11 CONTINUE
      EXECUTE HEAD
      IF(IND.EQ.123456)EXECUTE LIMITN
      IF(RUN.EQ.1)CALL PLOT(11,X,4100,2,4100,0,E,CO,DOT)
 1002 FORMAT (/,T2,I5,10F8.0)
 1333 FORMAT (T2,F8.2,2H| ,I4,2H| ,F11.1,2H| ,F8.1,2H| ,I3,2H||)
   44 FORMAT ('+',T48,80A1)
   66 FORMAT ('1',T30,'FE56 (P,GAMMA) CO57')
   77 FORMAT ('+',T30,'FE56 (P,GAMMA) CO57')
  102 FORMAT (//T2,128('.'))
  122 FORMAT (T2,128('.'))
 3122 FORMAT ('+',T9,120('.'))
 2122 FORMAT ('1',T47,A4,A4,/,T40,'THE UNCERTAINTY IS =',T62,F4.1)
 1311 FORMAT(' ',T1,6I5,6X,2F9.1,2X,'R->',F7.1,4X,I3,A2,F9.1,3F11.2
     *,1H%,5X,F6.3,/)
 1211 FORMAT(T1,' PEAK #  ____PEAK LIMITS_____          CNTRD     ECN
     *  TRANSITIN     LINE   RAW__COUNTS__CORR     ERROR        %ERR
     * EFF. FACT.')
  166 FORMAT ('+',50('_'))
  103 FORMAT (T3,'|ENERGY|',T11,'CH.#',T16,'|ACCUM.COUNTS|',
     CT33,'COUNTS|',T41,'|FACTOR|')
  163 FORMAT (T3,'|ENERGY|',T11,'CH.#',T16,'|ACCUM.COUNTS|',
     CT33,'COUNTS|',T41,'          ')
  104 FORMAT (T3,'| KEV. |',T11,'    ',T16,'|            |',
     CT33,'      |',T41,'|X2**N |')
  164 FORMAT (T3,'| KEV. |',T11,'    ',T16,'|            |',
     CT33,'      |',T41,'         ')
  106 FORMAT (T2,1H|,I3,A2,T10,1H|,F8.1,T22,1H|,F8.1,T33,1H|,F12.1,
     CT49,1H+,T48,F8.2,T59,1H|,F12.1,T75,1H+,T74,F8.2,T86,1H|,
     CF12.1,T101,1H+,T100,F8.2,T115,1H|,/'+',T49,1H_,T75,1H_,T101,1H
     C/T2,128('_'))
  206 FORMAT (T2,1H|,I3,A2,T10,1H|,F8.1,T22,1H|,F8.1,T33,1H|,F12.1,
     CT49,1H+,T48,F8.2,T59,1H|,F12.1,T75,1H+,T74,F8.2,T86,1H|,
     CF12.1,T101,1H+,T100,F8.2,T115,/'+',T49,1H_,T75,1H_,T101,1H_,
     C/T2,128('_'),/,T60,'AFTER EFFICIENCY CORRECTION',T90,F9.1,
     CT101,1H+,F8.1,T111,'OR',T114,1H+,F5.1,'%',/'+',T101,'_',
     CT114,'_',/T2,128('_'))
  107 FORMAT (1H ,1H|,'PEAK#',T10,1H|,' ENERGY ',T22,1H|,' CENTROID'
     C,T33,1H|,' # OF COUNTS IN ROW PEAK ',T59,1H|,'BACKGROUND UNDER

     C' THE PEAK',T86,1H|,'NET # OF COUNTS IN THE PEAK',T115,1H )
 2222 FORMAT (T40,'THE # OF THE INTEGRATED PEAKS =',I4)
 1222 FORMAT (1H )
  323 FORMAT (//,6I10,//)
 7533 FORMAT(/,' FROM',F8.1,' TO ',F8.1,A10,T40,A3,1H+,A3,1H+,A3,1H=
     *T70,F9.0,T83,1H+,F8.0,/'+',T83,1H_,7X,'  OR',T96,F6.2,'%',////
 7333 FORMAT(/,' FROM',F8.1,' TO ',F8.1,A10,T40,A3,1H=,
     *T70,F9.0,T83,1H+,F8.0,/'+',T83,1H_,7X,'  OR',T96,F6.2,'%',////
 7433 FORMAT(/,' FROM',F8.1,' TO ',F8.1,A10,T40,A3,1H+,A3,1H=,
     *T70,F9.0,T83,1H+,F8.0,/'+',T83,1H_,7X,'  OR',T96,F6.2,'%',////
 7766 FORMAT(T5,I4,10(F7.0))
      IF(RUN.EQ.1)EXECUTE PPLOT
      IF(RUN.EQ.2)EXECUTE PPLOT
      IF(RUN.LE.2)STOP
  222 EXECUTE PEAK
      STOP
C.....................................................
C.....................................................
C.....................................................
C     THE FOLLOWING BLOCK DOES THE FOLLOWING:
```

```
C     .....................................................
C     .....................................................
      IF(ISMTH.LT.1)GO TO 9211
      DO 7211 ISM=1,ISMTH
      CALL SMOOTH (CO   ,4100)
      PRINT,'CALL SMOOTH (CO   ,4100)'
 7211 CONTINUE
 9211 CONTINUE
C     .....................................................
C     .....................................................
C     .....................................................
      IF(RITE.NE.1)GO TO 3322
      DO 3321  NT=1,410
      L$=(NT-1)*10
      WRITE(9,7766)L$,(CO(L$+I4),I4=1,10)
      WRITE(6,*)L$
      WRITE(6,1002)L$,(CO(L$+I),I=1,10)
 3321 CONTINUE
 3322 CONTINUE
C     .....................................................
C     .....................................................
C     .....................................................
      READ(8,*)IND
      IF(RITE.EQ.1)WRITE(9,*)IND
      IF(IND.EQ.123456)EXECUTE LIMIT1
      IF(CAL.EQ.0)GO TO 756
      CALL CALIBR(AA,BB,CC,CO)
      IF(RITE.EQ.1)WRITE(9,*)AA,BB,CC
      GO TO 756
  756 WRITE(6,*)'AA = ',AA,'BB = ',BB,'CC = ',CC
      IF(RUN.EQ.0)EXECUTE HEAD
      WRITE(6,122)
      WRITE(6,163)
      WRITE(6,164)
      WRITE(6,122)
      ACCUM=0.
      DO 11 I=1,4100
      CH(I)=I
      IF(RUN.GE.2)E(I)=AA*FLOAT(I**2)+BB*FLOAT(I)+CC
      IF(RUN.LE.1)E(I)=0.
      X(I,1)=I
      TEMP=CO(I)
      IF(TEMP.LE.0.0)TEMP=1.
      IF(CO(I).LE.0.0)CO(I)=1.
      X(I,2)=ALOG10(TEMP)
      ACCUM=ACCUM+CO(I)
      ACC(I)=ACCUM
      NSTAR=IFIX(CO(I))
      IF(NSTAR.EQ.0)NSTAR=1
      N=0
      MULTIP(I)=N
      IF(NSTAR.LE.80)GO TO 1007
 1122 NSTAR=NSTAR/2
      MULTIP(I)=MULTIP(I)+1
      IF(NSTAR.GT.80)GO TO 1122
      NSTAR=80
 1007 DO 515 K=1,NSTAR
      STAR(I,K)=ST
  515 CONTINUE
      IF(NSTAR.GE.80)GO TO 11221
```

```
C                1- CALCULATES THE BACKGROUND
C                2- INTEGRATES THE PEAK
C                3- CALCULATES THE NET PEAK AREA
C                4- FINDS THE CENTROID OF THE PEAK
C.....
C.....
C.....
C   .DEFINITIONS.....                                    .....
C        NOP= # OF PEAKS
C A1...A6 = THE PEAK ATTRIBUTES
C        LB=AVERAGE BACKGROUND ON THE LEFT PER CHANNEL
C        RB=AVERAGE BACKGROUND ON THE RIGHT PER CHANNEL
C        RP(I1)=RAW # OF COUNTS IN THE PEAK
C        AB=AVERAGE BACKGROUND
C        PB(I1)=BACKGROUND COUNTS UNDER THE PEAK
C        PNET(I1)=NET # OF COUNTS IN THE PEAK
C        UB(I1)=UNCERTAINTY IN (PB(I1))
C        URP(I1)=UNCERTAINTY IN (RP(I1))
C        UPNET(I1)=UNCERTAINTY IN (PNET(I1))
C        CNTRD(I1)= CENTROID OF THE PEAK
C        ECNTRD(I1)= ENERGY AT THE CENTROID
C   .....
C   .....
C   .....
C*************************************************************************
C*************************************************************************
C*************************************************************************
      REMOTE BLOCK PEAK
      EXECUTE HEAD
      WRITE(6,122)
      CALL  LEVELS (LLEVEL,SPIN,NOL)
      PRINT66
      NOP=200
      NU=200
      IPC=0
      DO 105  I1=1,NOP
      READ(8,*)S1,A3,A4,S2,FACTOR
      ATEND,GO TO 1105
      IF(S1.EQ.123456.)GO TO 1105
      IF(A3.GT.0)GO TO 1411
      IF(S1.LT.0.)GO TO 7519
      A3=-A3
      S1=1
      A3=A3+1
      IF(S2.LT.0.0)A3=A3-1
1411  IF(A4.GT.0)GO TO 1511
      A4=-A4
      S2=1
      A4=A4-1
      IF(S2.LT.0.0)A4=A4+1
1511  X1(I1)=S1
      X2(I1)=A3
      X3(I1)=A4
      X4(I1)=S2
      X5(I1)=FACTOR
      X6(I1)=A4-A3
      IF(S1.LT.0.)GO TO 7519
      SC=A3-10
      DO 322 IC=1,50
      SC=SC+1
```

```
      T(IC,1)=SC
      T(IC,2)=CO(SC)
322   CONTINUE
7519  IF(RUN.LT.5)WRITE(6,2122)FIL,REC,ERR
      IF(RUN.GE.5)GO TO 3434
      WRITE(6,*)'
     #,'                    THE SERIAL # OF THE PEAK---> ',I1
3434  CONTINUE
      IF(RUN.LT.5)WRITE(6,*)'  '
      IF(RUN.LT.5)WRITE(6,*)S1,A3,A4,S2,FACTOR
      IF(RUN.LT.5)WRITE(6,*)'
      IF(S1.LT.0.)GO TO 7517
751   A1=A3-S1
      A2=A3-1
      A5=A4+1
      A6=A4+S2
      IF(RUN.LT.5)WRITE(6,*)'  '
      IF(RUN.LT.5)WRITE(6,*)A1,A2,A3,A4,A5,A6
      IF(RUN.LT.5)WRITE(6,*)'
      IF(S1.EQ.0.)GO TO 752
      IF(S2.EQ.0.)GO TO 753
      GO TO 754
752   A1=A5
      A2=A6
      GO TO 754
753   A5=A1
      A6=A2
754   LB=(ACC(A2)-ACC(A1-1))/((A2-A1)+1)
CC    WRITE(6,*)LB,'LB'
      RB=(ACC(A6)-ACC(A5-1))/((A6-A5)+1)
CC    WRITE(6,*)RB,'RB'
      AB=(LB+RB)/2
CC    WRITE(6,*)AB,'AB'
      RP(I1)=(ACC(A4)-ACC(A3-1))
      RP(I1)=RP(I1)*ABS(FACTOR)
CC    WRITE(6,*)RP(I1),'RP'
      PB(I1)=AB*((A4-A3)+1)*ABS(FACTOR)
CC    WRITE(6,*)PB(I1),'PB'
      IF(FACTOR.EQ.2.0)PNET(I1)=RP(I1)-PB(I1)-0.5*(CO(A3)-AB)
      IF(FACTOR.EQ.-2.0)PNET(I1)=RP(I1)-PB(I1)-0.5*(CO(A4)-AB)
      IF(FACTOR.EQ.1.0)PNET(I1)=RP(I1)-PB(I1)
C     WRITE(6,*)PNET(I1),'PNET'
      UB(I1)=SQRT(PB(I1))
      URP(I1)=SQRT(RP(I1))
      UPNET(I1)=SQRT(RP(I1)+PB(I1))
      GO TO 7518
7517  S1=ABS(S1)
      A1=A2=A5=A6=0.
      RP(I1)=(ACC(A4)-ACC(A3-1))
      PB(I1)=S1*(A4-A3+1)
      AB=PB(I1)/((A4-A3)+1)
      PNET(I1)=RP(I1)-PB(I1)
      UB(I1)=SQRT(PB(I1))
      URP(I1)=SQRT(RP(I1))
      UPNET(I1)=SQRT(RP(I1)+PB(I1))
7518  SUMX=0.
      SUM=0.
      DO 155 I2=A3,A4
      SUMX=SUMX+(CO(I2)-AB)*FLOAT(I2)
      SUM=SUM+(CO(I2)-AB)
```

```
  155 CONTINUE
      CNTRD(I1)=SUMX/SUM
      IF(FACTOR.EQ.-2.0)DEL=A4-CNTRD(I1)
      IF(FACTOR.EQ.-2.0)CNTRD(I1)=CNTRD(I1)+DEL
      IF(FACTOR.EQ. 2.0)DEL=CNTRD(I1)-A3
      IF(FACTOR.EQ. 2.0)CNTRD(I1)=CNTRD(I1)-DEL
      ECNTRD(I1)=AA*(CNTRD(I1)**2.)+BB*CNTRD(I1)+CC
C     ..................................................................
C     ..................................................................
C     ..................................................................
C       IF(RUN.LT.5)PRINT,' DO START'
      IFIND=0
      DO 5647 IS=1,NOL
      DIFF=ECNTRD(I1)-(RESON-LLEVEL(IS))
      IF(ABS(DIFF).LE.ERR)GO TO 5644
      IF(ECNTRD(I1).LT.1000.)GO TO 5643
      DIFF=DIFF+511.
      IF(ABS(DIFF).LE.ERR)GO TO 5645
      DIFF=DIFF+511.
      IF(ABS(DIFF).LE.ERR)GO TO 5646
      IF(IS.EQ.NOL.AND.IFIND.EQ.0)GO TO 5643
 5660 GO TO 5647
C     ..................................................................
C     ..................................................................
C     ..................................................................
 5644 PQ(I1)='PP'
      IF(RUN.LT.5)PRINT,'DIFF=  ',DIFF
      IF(RUN.LT.5)WRITE(6,*)'  '
      IF(RUN.LT.5)WRITE(6,*)'  '
      AQ(IS)=PQ(I1)
      Q(I1)=IS
      LEV(I1)=LLEVEL(IS)
      IF(RUN.LT.5)PRINT,IS,AQ(IS),LLEVEL(IS),'ASSS'
      IF(RUN.LT.5)WRITE(6,*)'  '
      GO TO 5649
C     ..................................................................
C     ..................................................................
C     ..................................................................
 5645 PQ(I1)='SS'
      IF(RUN.LT.5)PRINT,'DIFF=  ',DIFF
      AQ(IS)=PQ(I1)
      Q(I1)=IS
      LEV(I1)=LLEVEL(IS)
      IF(RUN.LT.5)PRINT,IS,AQ(IS),LLEVEL(IS),'ASSS'
      IF(RUN.LT.5)WRITE(6,*)'  '
      GO TO 5649
C     ..................................................................
C     ..................................................................
C     ..................................................................
 5646 PQ(I1)='DS'
      IF(RUN.LT.5)PRINT,'DIFF=  ',DIFF
      AQ(IS)=PQ(I1)
      Q(I1)=IS
      LEV(I1)=LLEVEL(IS)
      IF(RUN.LT.5)PRINT,IS,AQ(IS),LLEVEL(IS),'ASSS'
      IF(RUN.LT.5)WRITE(6,*)'  '
C     ..................................................................
C     ..................................................................
C     ..................................................................
 5649 IPC=IPC+1
```

```
      IFIND=IFIND+1
      IF(RUN.LT.5)PRINT,'IFIND = ',IFIND
      IF(RUN.LT.5)PRINT,'
      IF(RUN.LT.5)PRINT,'IPC =  ',IPC
      IF(RUN.LT.5)PRINT,'
      F(IPC)=IS
      FQ(IPC)=AQ(IS)
      FLEVEL(IPC)=LLEVEL(IS)
      FCNTRD(IPC)=ECNTRD(I1)
      FNTRD(IPC)=CNTRD(I1)
      FP(IPC)=RP(I1)
      FRP(IPC)=URP(I1)
      FPB(IPC)=PB(I1)
      FUB(IPC)=UB(I1)
      FPNET(IPC)=PNET(I1)
      FUPNET(IPC)=UPNET(I1)
      FX1(IPC)=X1(I1)
      FX2(IPC)=X2(I1)
      FX3(IPC)=X3(I1)
      FX4(IPC)=X4(I1)
      FX5(IPC)=X5(I1)
      FX6(IPC)=X6(I1)
      IF(RUN.LT.5)WRITE(6,107)
      IF(RUN.LT.5)WRITE(6,106)F(IPC),FQ(IPC),FCNTRD(IPC),FNTRD(IPC)
     *,FP(IPC),FRP(IPC),FPB(IPC),FUB(IPC),FPNET(IPC),FUPNET(IPC)
      IF(RUN.LT.5)PRINT,'
 5647 CONTINUE
      GO TO 3752
C     ..................................................
C     ..................................................
C     ..................................................
5643  IPC=IPC+1
      IF(RUN.LT.5)PRINT,'IFIND = ',IFIND
      IF(RUN.LT.5)PRINT,'
      IF(RUN.LT.5)PRINT,'IPC =  ',IPC
      IF(RUN.LT.5)PRINT,'
      PQ(I1)='UN'
      IF(RUN.LT.5)PRINT,'DIFF=  ',DIFF
      IF(RUN.LT.5)PRINT,'
      NU=NU+1
      AQ(IS)=PQ(I1)
      Q(I1)=NU
C     PRINT,NU
      LEV(I1)=-ECNTRD(I1)
      IF(RUN.LT.5)PRINT,IS,AQ(IS),LLEVEL(IS),'ASSS'
      IF(RUN.LT.5)WRITE(6,*)'
C     ..................................................
C     ..................................................
C     ..................................................
      F(IPC)=NU
      FQ(IPC)=AQ(IS)
      FLEVEL(IPC)=LEV(I1)
      FCNTRD(IPC)=ECNTRD(I1)
      FNTRD(IPC)=CNTRD(I1)
      FP(IPC)=RP(I1)
      FRP(IPC)=URP(I1)
      FPB(IPC)=PB(I1)
      FUB(IPC)=UB(I1)
      FPNET(IPC)=PNET(I1)
      FUPNET(IPC)=UPNET(I1)
```

```
      FX1(IPC)=X1(I1)
      FX2(IPC)=X2(I1)
      FX3(IPC)=X3(I1)
      FX4(IPC)=X4(I1)
      FX5(IPC)=X5(I1)
      FX6(IPC)=X6(I1)
C     ..........................................................
C     ..........................................................
C     ..........................................................
 3752 IF(RUN.GE.5)GO TO 105
      WRITE(6,2122)FIL,REC,ERR
      WRITE(6,122 )
      WRITE(6,107)
      WRITE(6,122)
      WRITE(6,106)Q(I1),PQ(I1),ECNTRD(I1),CNTRD(I1),RP(I1),URP(I1),
     *PB(I1),UB(I1),PNET(I1),UPNET(I1)
      WRITE(6,1222 )
      WRITE(6,122 )
      IF(RUN.LT.5)WRITE(6,103)
 5117 IF(RUN.LT.5)WRITE(6,104)
      AT1=A3-10
      AT2=A4+10
      IF((AT2-AT1).GT.45)AT2=AT2-10
      JC=1
      DO 1555 IJ=AT1,AT2
C     WRITE(6,*)'JC= ',JC
      T(JC,1)=IJ
      T(JC,2)=CO(IJ)
      JC=JC+1
      NSTAR=IFIX(CO(IJ))
      IF(NSTAR.EQ.0)NSTAR=1
      N=0
      MULTIP(IJ)=N
 1111 IF(NSTAR.LT.80)GO TO 1000
      NSTAR=NSTAR/2
      MULTIP(IJ)=MULTIP(IJ)+1
      IF(NSTAR.GT.80)GO TO 1111
 1000 DO 555 K=1,NSTAR
      STAR(IJ,K)=ST
  555 CONTINUE
      IF(RUN.LT.5)WRITE(6,1333)E(IJ),CH(IJ),ACC(IJ),CO(IJ),MULTIP(IJ
      IF(RUN.LT.5)WRITE(6,44)(STAR(IJ,L),L=1,NSTAR)
      IF(RUN.LT.5)WRITE(6,166)
 1555 CONTINUE
C     WRITE(6,323)A1,A2,A3,A4,A5,A6
C     WRITE(6,122)
C     WRITE(6,122)
C     WRITE(6,122)
      IF(RUN.LT.5)CALL PLOT(10,T,50,2,51,0,E,CO,DOT)
  105 CONTINUE
 1105 CONTINUE
      NOP=I1-1
      WRITE(6,2122)FIL,REC,ERR
      DO 800 I2=1,NOP
      WRITE(6,1321)I2,X1(I2),X2(I2),X3(I2),X4(I2),X5(I2),X6(I2)
 800  CONTINUE
 1321 FORMAT(T2,5G8.1,2G12.1,/)
      WRITE(6,2122)FIL,REC,ERR
      DO 3751 IR=1,IPC
      Q(IR)=F(IR)
```

```
      PQ(IR)=FQ(IR)
      LEV(IR)=FLEVEL(IR)
      ECNTRD(IR)=FCNTRD(IR)
      CNTRD(IR)=FNTRD(IR)
      RP(IR)=FP(IR)
      URP(IR)=FRP(IR)
      PB(IR)=FPB(IR)
      UB(IR)=FUB(IR)
      PNET(IR)=FPNET(IR)
      UPNET(IR)=FUPNET(IR)
      X1(IR)=FX1(IR)
      X2(IR)=FX2(IR)
      X3(IR)=FX3(IR)
      X4(IR)=FX4(IR)
      X5(IR)=FX5(IR)
      X6(IR)=FX6(IR)
      IF(RUN.LT.5)WRITE(6,106)Q(IR),PQ(IR),ECNTRD(IR),CNTRD(IR),RP(I
     *,URP(IR),PB(IR),UB(IR),PNET(IR),UPNET(IR)
3751  CONTINUE
      IF(RITE.EQ.1)WRITE(9,*)NOP
      WRITE(6,*)NOP
      WRITE(6,*)'     ..........................................'
      WRITE(6,*)'      ..........................................'
      WRITE(6,*)'       ..........................................'
      WRITE(6,*)'      ..........................................'
      WRITE(6,*)'      ..........................................'
      WRITE(6,*)'..............................'
      WRITE(6,*)'..............................'
      WRITE(6,2222)NOP
      WRITE(6,*)'..............................'
      WRITE(6,*)'..............................'
      WRITE(6,*)'      ..........................................'
      WRITE(6,*)'       ..........................................'
      WRITE(6,*)'      ..........................................'
      WRITE(6,*)'     ..........................................'
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC   OK
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC   OK
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC   OK
      NOP=IPC
      WRITE(6,2122)FIL,REC,ERR
      PRINT,'          Q',                PQ','          LEV',
     $'          ECNTRD'
      DO 2314 I7=1,NOP
      WRITE(6,122)
      PRINT,I7,Q(I7),PQ(I7),LEV(I7),ECNTRD(I7)
 2314 CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC   OK
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC   OK
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC   OK
      DO 7123  IE=1,NOP
      IF(RUN.LT.3)GO TO 7123
CC    PRINT,'GOING TO EFFI'
      EXECUTE EFFI
C     WRITE(6,206)Q(IE),PQ(IE),ECNTRD(IE),CNTRD(IE),RP(IE),URP(IE),
C    *PB(IE),UB(IE),PNET(IE),UPNET(IE),CPK(IE),UCPK(IE),UPERC(IE)
7123  CONTINUE
      IF(RUN.GE.6)GO TO 2324
      WRITE(6,2122)FIL,REC,ERR
      PRINT,'          Q',                PQ','          LEV',
     $'          ECNTRD'
```

```
      DO 1314 I7=1,NOP
      WRITE(6,122)
      IF(LEV(I7).LT.0.0)PRINT,I7,Q(I7),PQ(I7),LEV(I7),ECNTRD(I7)
 1314 CONTINUE
 2324 CONTINUE
CCCCCCC   OK
CCCCCCC   OK
CCCCCCC   OK
      IF(RUN.LE.2)GO TO 8222
      LINE=NOL
      IF(RUN.GE.6)GO TO 8222
      EXECUTE HEAD
      WRITE(6,2122)FIL,REC,ERR
      DO 7222 LN=1,300
      NS=0
      TOTC=0.
      UT=0.0
      DO 7111 IT=1,NOP
      IF(Q(IT).NE.LN)GO TO 7111
      WRITE(6,107 )
      WRITE(6,122 )
      WRITE(6,206)Q(IT),PQ(IT),ECNTRD(IT),CNTRD(IT),RP(IT),URP(IT),
     *PB(IT),UB(IT),PNET(IT),UPNET(IT),CPK(IT),UCPK(IT),UPERC(IT)
      TOTC=TOTC+CPK(IT)
      IF(PQ(IT).EQ.'PP')GO TO 7331
      IF(PQ(IT).EQ.'SS')GO TO 7331
      IF(PQ(IT).EQ.'DS')GO TO 7331
CC
      WRITE(6,1222)
      WRITE(6,1222)
      WRITE(6,*)'IF THE PEAK IS A PP'
      WRITE(6,1222)
      WRITE(6,*)'LOOK FOR THE FOLLOWING GAMMA RAYS:'
      WRITE(6,1222)
      EG1=ECNTRD(IT)-511.
      EG2=EG1-511.
      WRITE(6,1222)
      WRITE(6,*)'SS  ',EG1
      WRITE(6,1222)
      WRITE(6,*)'DS  ',EG2
      WRITE(6,1222)
      WRITE(6,1222)
CC
CC    WRITE(6,*)'LOOK FOR THE FOLLOWING GAMMA RAYS:'
      WRITE(6,*)'IF THE PEAK IS A SS'
      WRITE(6,1222)
      WRITE(6,*)'LOOK FOR THE FOLLOWING GAMMA RAYS:'
      WRITE(6,1222)
      EG0=ECNTRD(IT)+511.
      EG2=EG0-511.-511
      WRITE(6,1222)
      WRITE(6,*)'PP  ',EG0
      WRITE(6,1222)
      WRITE(6,*)'DS  ',EG2
      WRITE(6,1222)
      WRITE(6,1222)
CC
      WRITE(6,*)'IF THE PEAK IS A DS'
      WRITE(6,1222)
      WRITE(6,*)'LOOK FOR THE FOLLOWING GAMMA RAYS:'
```

```
      WRITE(6,1222)
      EG0=ECNTRD(IT)+511.+511.
      EG1=EG0-511.
      WRITE(6,1222)
      WRITE(6,*)'PP  ',EG0
      WRITE(6,1222)
      WRITE(6,*)'SS  ',EG1
CC
CC    WRITE(6,2122)FIL,REC,ERR
      GO TO 7111
7331  NS=NS+1
      SQ(NS)=PQ(IT)
      UT=UT+UCPK(IT)**2
      TRANS=LEV(IT)
7111  CONTINUE
      UTOT=SQRT(UT)
      IF(TOTC.EQ.0.)GO TO 7222
      UREL=UTOT/TOTC*100
      IF(NS.EQ.3)WRITE(6,7533)RESON,TRANS,SPIN(LN),SQ(1),SQ(2),SQ(3)
     $,TOTC,UTOT,UREL
      IF(NS.EQ.2)WRITE(6,7433)RESON,TRANS,SPIN(LN),SQ(1),SQ(2)
     $,TOTC,UTOT,UREL
      IF(NS.EQ.1)WRITE(6,7333)RESON,TRANS,SPIN(LN),SQ(1)
     $,TOTC,UTOT,UREL
      WRITE(6,122)
      IF(NS.EQ.0)GO TO 7227
      EG0=RESON-TRANS
      EG1=EG0-511.
      EG2=EG1-511.
      WRITE(6,*)'THE EXPECTED GAMMA RAYS ARE:'
      WRITE(6,1222)
      WRITE(6,*)'          PP                    SS
      WRITE(6,1222)
      WRITE(6,*)EG0,EG1,EG2
      WRITE(6,1222)
7227  WRITE(6,2122)FIL,REC,ERR
7222  CONTINUE
8222  CONTINUE
      WRITE(6,2122)FIL,REC,ERR
      WRITE(6,1211)
      DO 1124 IN=1,NOP
      IF(IN.EQ.18)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.36)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.54)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.72)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.90)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.108)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.126)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.144)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.162)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.180)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.198)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.216)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.234)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.252)WRITE(6,2122)FIL,REC,ERR
      IF(IN.EQ.18)WRITE(6,1211)
      IF(IN.EQ.36)WRITE(6,1211)
      IF(IN.EQ.54)WRITE(6,1211)
      IF(IN.EQ.72)WRITE(6,1211)
      IF(IN.EQ.90)WRITE(6,1211)
```

```
      IF(IN.EQ.108)WRITE(6,1211)
      IF(IN.EQ.126)WRITE(6,1211)
      IF(IN.EQ.144)WRITE(6,1211)
      IF(IN.EQ.162)WRITE(6,1211)
      IF(IN.EQ.180)WRITE(6,1211)
      IF(IN.EQ.198)WRITE(6,1211)
      IF(IN.EQ.216)WRITE(6,1211)
      IF(IN.EQ.234)WRITE(6,1211)
      IF(IN.EQ.252)WRITE(6,1211)
      WRITE(6,122)
      EFFM=CPK(IN)/PNET(IN)
      WRITE(6,1311)IN,X1(IN),X2(IN),X3(IN),X4(IN),X5(IN),CNTRD(IN),
     *ECNTRD(IN),LEV(IN),Q(IN),PQ(IN),PNET(IN),CPK(IN),UCPK(IN)
     *,UPERC(IN),EFFM
      IF(RITE.EQ.1)WRITE(9,75174)CNTRD(IN),ECNTRD(IN),LEV(IN),PQ(IN)
     *Q(IN)
75174 FORMAT(T2,3F8.1,A2,I3)
      IF(RITE.EQ.2)WRITE(81,*)ECNTRD(IN),CNTRD(IN),CPK(IN),UPERC(IN)
 1124 CONTINUE
      WRITE(6,2122)FIL,REC,ERR
      END BLOCK
C*********************************************************************
C*********************************************************************
C*********************************************************************
      REMOTE BLOCK EFFI
CC    PRINT,'Q   ',' PQ  ',' LEV   ',' ECNTRD'
CC    PRINT,Q(IE),PQ(IE),LEV(IE),ECNTRD(IE)
C     WRITE(6,*)PQ(IE),ECNTRD(IE),PNET(IE),UPNET(IE),'START E NET U
      IF(PQ(IE).EQ.'SS')ECNTRD(IE)=ECNTRD(IE)+511.
      IF(PQ(IE).EQ.'DS')ECNTRD(IE)=ECNTRD(IE)+2.*511.
      IF(ECNTRD(IE).GT.12000.)GO TO 1761
      IF(ECNTRD(IE).LT.2600.)GO TO 1761
      IF(EFFCOR.EQ.'NO')GO TO 1761
      RI=61.0-0.005*ECNTRD(IE)
C...RI=
CC    WRITE(6,*)RI,'RI'
      IRL=INT(RI)
CC    WRITE(6,*)IRL,'IRL'
      IRU=IRL+1
CC    WRITE(6,*)IRU,'IRU'
      RL=IRL
CC    WRITE(6,*)RL,'RL'
      DIF=RI-RL
CC    WRITE(6,*)DIF,'DIF'
      IF(PQ(IE).EQ.'SS')GO TO 325
      IF(PQ(IE).EQ.'DS')GO TO 326
      PPE(IE)=FEP(IRL)+DIF*(FEP(IRU)-FEP(IRL))
      EFSH(IE)=PPE(IE)
      CPK(IE)=PNET(IE)/PPE(IE)*100.
      UCPK(IE)=UPNET(IE)/PNET(IE)*CPK(IE)
      UPERC(IE)=UPNET(IE)/PNET(IE)*100.
CC    WRITE(6,*)Q(IE),PQ(IE),PPE(IE),CPK(IE),UCPK(IE),UPERC(IE)
      GO TO 327
326   DSE(IE)=DEP(IRL)+DIF*(DEP(IRU)-DEP(IRL))
      EFSH(IE)=DSE(IE)
      CPK(IE)=PNET(IE)/DSE(IE)*100.
      UCPK(IE)=UPNET(IE)/PNET(IE)*CPK(IE)
      UPERC(IE)=UPNET(IE)/PNET(IE)*100.
CC    WRITE(6,*)Q(IE),PQ(IE),DSE(IE),CPK(IE),UCPK(IE),UPERC(IE)
      GO TO 327
```

```
325   DSE(IE)=DEP(IRL)+DIF*(DEP(IRU)-DEP(IRL))
      EFSH(IE)=DSE(IE)
      CPK(IE)=PNET(IE)/DSE(IE)*100.*0.97
      UCPK(IE)=UPNET(IE)/PNET(IE)*CPK(IE)
      UPERC(IE)=UPNET(IE)/PNET(IE)*100.
CC    WRITE(6,*)(IE),PQ(IE),DSE(IE),CPK(IE),UCPK(IE),UPERC(IE)
      GO TO 327
1761  IF(PQ(IE).EQ.'PP')PQ(IE)='PP'
      IF(PQ(IE).EQ.'SS')PQ(IE)='SS'
      IF(PQ(IE).EQ.'DS')PQ(IE)='DS'
      IF(PQ(IE).EQ.'UN')PQ(IE)='NU'
      CPK(IE)=PNET(IE)
      UCPK(IE)=UPNET(IE)
      UPERC(IE)=UPNET(IE)/PNET(IE)*100.
327   CONTINUE
      IF(PQ(IE).EQ.'SS')FULL(IE)=ECNTRD(IE)
      IF(PQ(IE).EQ.'SS')ECNTRD(IE)=ECNTRD(IE)-511.
      IF(PQ(IE).EQ.'DS')FULL(IE)=ECNTRD(IE)
      IF(PQ(IE).EQ.'DS')ECNTRD(IE)=ECNTRD(IE)-2.*511.
      IF(PQ(IE).EQ.'PP')FULL(IE)=ECNTRD(IE)
      IF(PQ(IE).EQ.'UN')FULL(IE)=ECNTRD(IE)
C     WRITE(6,*)'EFFICIENCY CHECK'
C     WRITE(6,*)IE
C     WRITE(6,*)'Q(IE)','PQ(IE)','ECNTRD(IE)','FULL(IE)','EFSH(IE)'
C     WRITE(6,*)(IE),PQ(IE),ECNTRD(IE),FULL(IE),EFSH(IE)
      END BLOCK
C*********************************************************************
C*********************************************************************
C*********************************************************************
      REMOTE BLOCK PPLOT
      EXECUTE HEAD
      MC=0
      DO 108 J=1,4096,128
      MC=MC+1
      J1=0
      DO 109 J2=1,128
      J1=J2+(MC-1)*128
      IF(J1.GT.4100)J1=4100
      A(J2,1)=J1
      TEMP=CO(J1)
      IF(TEMP.LE.0.0)TEMP=1.
      A(J2,2)=TEMP
C     WRITE(6,*)MC,J,J1,J2,A(J2,1),A(J2,2)
  109 CONTINUE
      WRITE(6,3122)
      CALL SPLOT(MC,A,128,2,128,0,E,CO,DOT)
  108 CONTINUE
      END BLOCK
C*********************************************************************
C*********************************************************************
C*********************************************************************
      REMOTE BLOCK LIMIT1
      EXECUTE HEAD
      WRITE(6,*)' DATA INPUT IS VERIFIED'
      WRITE(6,*)'    DATA INPUT IS VERIFIED'
      WRITE(6,*)'       DATA INPUT IS VERIFIED'
      WRITE(6,*)'          DATA INPUT IS VERIFIED'
      WRITE(6,*)'             DATA INPUT IS VERIFIED'
      WRITE(6,*)'                DATA INPUT IS VERIFIED'
      WRITE(6,*)'                   DATA INPUT IS VERIFIED'
```

```
      WRITE(6,*)'                    DATA INPUT IS VERIFIED'
      WRITE(6,*)'                      DATA INPUT IS VERIFIED'
      WRITE(6,*)'                        DATA INPUT IS VERIFIED
      WRITE(6,*)'                          DATA INPUT IS VERIF
      WRITE(6,*)'                         DATA INPUT IS VERIFI
      WRITE(6,*)'                          DATA INPUT IS VERIF
      WRITE(6,*)'                        DATA INPUT IS VERIFIED
      WRITE(6,*)'                      DATA INPUT IS VERIFIED'
      WRITE(6,*)'                    DATA INPUT IS VERIFIED'
      WRITE(6,*)'                  DATA INPUT IS VERIFIED'
      WRITE(6,*)'                DATA INPUT IS VERIFIED'
      WRITE(6,*)'              DATA INPUT IS VERIFIED'
      WRITE(6,*)'            DATA INPUT IS VERIFIED'
      WRITE(6,*)'          DATA INPUT IS VERIFIED'
      WRITE(6,*)'        DATA INPUT IS VERIFIED'
      WRITE(6,*)'      DATA INPUT IS VERIFIED'
      END BLOCK
C*********************************************************************
C*********************************************************************
C*********************************************************************
      REMOTE BLOCK LIMITN
      EXECUTE HEAD
      WRITE(6,*)ACC(4100)
      WRITE(6,*)ACC(4100)
      WRITE(6,*)ACC(4100),'       A          CCCCC      CCCCC'
      WRITE(6,*)ACC(4100),'      A A        C          C     '
      WRITE(6,*)ACC(4100),'     A   A      C          C'
      WRITE(6,*)ACC(4100),'    A     A     C          C'
      WRITE(6,*)ACC(4100),'   AAAAAAAAA     C          C'
      WRITE(6,*)ACC(4100),'  A         A    C          C'
      WRITE(6,*)ACC(4100),' AA         AA    CCCCC      CCCCC'
      WRITE(6,*)ACC(4100)
      WRITE(6,*)ACC(4100)
      WRITE(6,*)ACC(4100)
      WRITE(6,*)ACC(4100)
      WRITE(6,*)ACC(4100)
      WRITE(6,*)ACC(4100)
      WRITE(6,*)ACC(4100)
      WRITE(6,*)ACC(4100)
      END BLOCK
C*********************************************************************
C*********************************************************************
C*********************************************************************
      REMOTE BLOCK LIMITN
      REMOTE BLOCK HEAD
      WRITE(6,66)
      WRITE(6,77)
      DO 1092 LI=1,12
      WRITE(6,*)'.....',FIL,' ',REC,'.....'
1092  CONTINUE
      WRITE(6,*)'DATE          =                 .....'
      WRITE(6,*)'NMR FREQUANCY=                   .....'
      WRITE(6,*)'Q             =        MICRO C.    .....'
      WRITE(6,*)'ANGLE         =       DEG.    .....'
      WRITE(6,*)'RESONANCE #   =          .....'
      WRITE(6,*)'PROTON ENERGY=             KEV.    .....'
      WRITE(6,*)'EX ENERGY     =           KEV.    .....'
      WRITE(6,*)'.....'
      WRITE(6,*)'.....'
      WRITE(6,*)'.....'
      WRITE(6,*)'..CALIBRATION POINTS:  CH#         ENERGY KEV..'
```

```
      WRITE(6,*)'.....',
      WRITE(6,*)'.....',
      WRITE(6,*)'.....',
      WRITE(6,*)'.....',
      WRITE(6,*)'.....',
      WRITE(6,*)'.....',
      WRITE(6,*)'.....',
      WRITE(6,*)'.....'
      WRITE(6,122)
      WRITE(6,122)
      WRITE(6,122)
      WRITE(6,122 )
      WRITE(6,102 )
      WRITE(6,102)
      END BLOCK
C*********************************************************************
C*********************************************************************
C*********************************************************************
      END
C*********************************************************************
C*********************************************************************
C*********************************************************************
C*********************************************************************
C*********************************************************************
C---------------------------------------------------------------
C
C                    SUBROUTINE PLOT
C
C---------------------------------------------------------------
C
C     CALL PLOT (NO,A,N,M,NL,NS)
C
C     DESCRIPTION OF VARIOUS PARAMETERS:
C
C     NO - CHART NUMBER (3 DIGITS MAXIMUM)
C
C     A  - MATRIX OF DATA TO BE PLOTTED. FIRST COLUMN REPRESENTS
C          BASE VARIABLE AND SUCCESSIVE COLUMNS ARE THE CROSS-
C          VARIABLES (MAXIMUM IS 9)
C
C     N -  NUMBER OF ROWS IN MATRIX A (THERE IS NO LIMIT ON THIS)
C
C     M -  NUMBER OF COLUMNS IN MATRIX A (EQUAL TO THE TOTAL
C          NUMBER OF VARIABLES). MAXIMUM IS 10
C
C     NL - NUMBER OF LINES IN THE PLOT. IF 0 IS SPECIFIED, 50
C          LINES ARE USED( USUALLY TAKE NL = N ----- BUT IN NO CASE
C          N > NL; HOWEVER   N <= NL  CAN WORK. FOR NL=0, THE GRAPH
C          IS CONFINED TO A SINGLE PAGE)
C
C     NS - CODE FOR SORTING THE BASE VARIABLE DATA IN ASCENDING
C          ORDER
C
C            0   SORTING IS NOT NECESSARY (ALREADY IN ASCENDING
C                ORDER (0 OR ANY NEGATIVE INTEGER)
C            1   SORTING IS NECESSARY ( 1 OR ANY POSITIVE INTEGER)
C
C---------------------------------------------------------------
C
C
      SUBROUTINE PLOT(NO,A,N,M,NL,NS,E,CO,DOT)
```

```
      DIMENSION OUT(101),YPR(11),ANG(9),A(1),E(4100),CO(4100)
      CHARACTER*1 DOT(101)
C
C
C       THE CHARACTERS FOR THE GRAPHS CAN BE CHANGED ALSO ------
C       FOLLOWING DATA STATEMENT.
C
C
      DATA BLANK/' '/,ANG/'*','B','C','D','E','F','G','H',' '/
    1 FORMAT(1H1,40X,'CHART # ',I3,T90,'      --------->>')
  166 FORMAT ('+',T9,101A1)
    2 FORMAT(1H ,F8.1,1X,1H|,100A1,2X,F8.1,1H|,F8.0)
    3 FORMAT(1H )
    7 FORMAT(1H ,16X,101H.          .          .          .
     @                .          .          .          .)
  177 FORMAT('+',15X,99('-'))
C
C       FORMAT STATMENT FOR Y-AXIS
C
    8 FORMAT(1H ,9X,11F10.2)
      ITT=0
      NLL=NL
C
C
      IF(NS) 16, 16, 10
C
C       SORT BASE VARIABLE IN ASCENDING ORDER
C
   10 DO 15 I=1,N
      DO 14 J=I,N
      IF(A(I)-A(J)) 14, 14, 11
   11 L=I-N
      LL=J-N
      DO 12 K=1,M
      L=L+N
      LL=LL+N
      F=A(L)
      A(L)=A(LL)
   12 A(LL)=F
   14 CONTINUE
   15 CONTINUE
C
C         TEST NLL
C
   16 IF(NLL) 20, 18, 20
   18 NLL=50
C
C         WRITE TITLE
C
   20 WRITE(6,1)NO
C
C         FIND SCALE FOR BASE VARIABLE
C
      XSCAL=(A(N)-A(1))/(FLOAT(NLL-1))
C
C         FIND SCALE FOR CROSS-VARIABLES
C
      M1=N+1
      YMIN=A(M1)
      YMAX=YMIN
```

```
      M2=M*N
      DO 40 J=M1,M2
      IF(A(J)-YMIN) 28,26,26
   26 IF(A(J)-YMAX) 40,40,30
   28 YMIN=A(J)
      GO TO 40
   30 YMAX=A(J)
   40 CONTINUE
      YSCAL=(YMAX-YMIN)/100.00
C
C       WRITE(6,*) CROSS-VARIABLE NUMBERS
C
      YPR(1)=YMIN
      DO 90 KN=1,9
   90 YPR(KN+1)=YPR(KN)+YSCAL*10.0
      YPR(11)=YMAX
      WRITE(6,8)(YPR(IP),IP=1,11)
      WRITE(6,7)
C
C       FIND BASE VARIABLE PRINT POSITION
C
      XB=A(1)
      L=1
      MY=M-1
      I=1
   45 F=I-1
      XPR=XB+F*XSCAL
      IF(A(L)-XPR) 50,50,70
C
C       FIND CROSS-VARIABLES
C
   50 DO 55 IX=1,101
   55 OUT(IX)=BLANK
      DO 60 J=1,MY
      LL=L+J*N
      JP=((A(LL)-YMIN)/YSCAL)+1.0
      OUT(JP)=ANG(J)
   60 CONTINUE
C
C       FINDING AXIS FOR BASE VARIABLE.
C
      IF(YMIN.GT.0.)GO TO 100
      KP=1.-YMIN/YSCAL
      OUT(KP)=ANG(9)
C
C       PRINT LINE AND CLEAR, OR SKIP
C
  100 ITT=IFIX(XPR)
      IF(ITT.GT.4100)ITT=1
      WRITE(6,2)XPR,(OUT(IZ),IZ=2,101),E(ITT),CO(ITT)
      WRITE(6,166)(DOT(ID),ID=1,JP)
C     WRITE(6,166)
      WRITE(6,177)
      L=L+1
      GO TO 80
   70 WRITE(6,3)
   80 I=I+1
      IF(I-NLL) 45, 84, 86
   84 XPR=A(N)
      GO TO 50
```

```
C
C       WRITE    CROSS-VARIABLE NUMBERS AGAIN
C
  86  WRITE(6,7)
      WRITE(6,8)(YPR(IP),IP=1,11)
C
C
      RETURN
      END
C*********************************************************************
C*********************************************************************
C*********************************************************************
C*********************************************************************
C*********************************************************************
      SUBROUTINE SPLOT(NO,A,N,M,NL,NS,E,CO,DOT)
      DIMENSION OUT(101),YPR(11),ANG(9),A(1),E(4100),CO(4100)
      CHARACTER*1 DOT(101)
C
C
C       THE CHARACTERS FOR THE GRAPHS CAN BE CHANGED ALSO ------ IN
C       FOLLOWING DATA STATEMENT.
C
C
      DATA BLANK/' '/,ANG/'*','B','C','D','E','F','G','H','|'/
C  1  FORMAT(1H1,40X,'CHART # ',I3,T90,'      --------->>')
  166 FORMAT ('+',T9,101A1)
    2 FORMAT(1H ,F8.1,1X,1H|,100A1,2X,F8.1,1H|,F8.0)
    3 FORMAT(1H )
C   7 FORMAT(1H ,16X,101H.          .         .         .         .
     @   .         .         .         .         .         .)
C
C       FORMAT STATMENT FOR Y-AXIS
C
      ITT=0
      NLL=NL
C
C
      IF(NS) 16, 16, 10
C
C       SORT BASE VARIABLE IN ASCENDING ORDER
C
  10  DO 15 I=1,N
      DO 14 J=I,N
      IF(A(I)-A(J)) 14, 14, 11
  11  L=I-N
      LL=J-N
      DO 12 K=1,M
      L=L+N
      LL=LL+N
      F=A(L)
      A(L)=A(LL)
  12  A(LL)=F
  14  CONTINUE
  15  CONTINUE
C
C         TEST NLL
C
  16  IF(NLL) 20, 18, 20
  18  NLL=50
C
```

```
C          WRITE(6,*) TITLE
C
C 20  WRITE(6,1)NO
C
C          FIND SCALE FOR BASE VARIABLE
C
   20  XSCAL=(A(N)-A(1))/(FLOAT(NLL-1))
C
C          FIND SCALE FOR CROSS-VARIABLES
C
       M1=N+1
       YMIN=A(M1)
       YMAX=YMIN
       M2=M*N
       DO 40 J=M1,M2
       IF(A(J)-YMIN) 28,26,26
   26  IF(A(J)-YMAX) 40,40,30
   28  YMIN=A(J)
       GO TO 40
   30  YMAX=A(J)
   40  CONTINUE
       YSCAL=(YMAX-YMIN)/100.00
C
C          WRITE(6,*) CROSS-VARIABLE NUMBERS
C
       YPR(1)=YMIN
       DO 90 KN=1,9
   90  YPR(KN+1)=YPR(KN)+YSCAL*10.0
       YPR(11)=YMAX
C      WRITE(6,8)(YPR(IP),IP=1,11)
C      WRITE(6,7)
C
C          FIND BASE VARIABLE WRITE(6,*) POSITION
C
       XB=A(1)
       L=1
       MY=M-1
       I=1
   45  F=I-1
       XPR=XB+F*XSCAL
       IF(A(L)-XPR) 50,50,70
C
C          FIND CROSS-VARIABLES
C
   50  DO 55 IX=1,101
   55  OUT(IX)=BLANK
       DO 60 J=1,MY
       LL=L+J*N
       JP=((A(LL)-YMIN)/YSCAL)+1.0
       OUT(JP)=ANG(J)
   60  CONTINUE
C
C          FINDING AXIS FOR BASE VARIABLE.
C
       IF(YMIN.GT.0.)GO TO 100
       KP=1.-YMIN/YSCAL
       OUT(KP)=ANG(9)
C
C          WRITE(6,*) LINE AND CLEAR, OR SKIP
C
```

```
 100  ITT=IFIX(XPR)
C      WRITE(6,*)ITT
       WRITE(6,2)XPR,(OUT(IZ),IZ=2,101),E(ITT),CO(ITT)
       WRITE(6,166)(DOT(ID),ID=1,JP)
C      WRITE(6,166)
       L=L+1
       GO TO 80
  70   WRITE(6,3)
  80   I=I+1
       IF(I-NLL) 45, 84, 86
  84   XPR=A(N)
       GO TO 50
C
C        WRITE(6,*) CROSS-VARIABLE NUMBERS AGAIN
C
C 86   WRITE(6,7)
C      WRITE(6,8)(YPR(IP),IP=1,11)
C
C
  86   RETURN
       END
C*********************************************************************
C*********************************************************************
C*********************************************************************
C*********************************************************************
C*********************************************************************
C  CALIBR PROGRAM
       SUBROUTINE CALIBR (AA, BB, CC,CO )
C
       DIMENSION  W(50) , F(3,50), U(50), P(4,4),Q(4,9),T1(4),
      1 B(4), B1(4), NUM(4) ,CO(4100),SPEC (4100) ,  C(4)
       DIMENSION COEFF(3,20), TITLE(5,20), IANGL(20)
       LUNC  =  5
       LUNT  =  6
       LUNP  =  7
     1 NSPEC=1
       WRITE(6,*)NSPEC
       IF(NSPEC) 8000,8000, 8001
 8000 WRITE(6,6003)
       CALL EXIT
 8001 WRITE(6,6003)
       DO 6000 LSPEC = 1, NSPEC
       NFIRS=1
       NLAST=4100
       CHECK=2
       TMC=0
C      READ(8,*) NFIRS, NLAST, E1, E2, E3, E4, CHECK, TMC
C      WRITE(6,*)NFIRS, NLAST, E1, E2, E3, E4, CHECK, TMC
C      READ(8,*)IANGL(LSPEC), (TITLE(I,LSPEC), I = 1, 5)
C      WRITE(6,*)IANGL(LSPEC), (TITLE(I,LSPEC), I = 1, 5)
C      READ(8,*)( B1(I) , NUM(I) , I = 1 , 4 )
       READ(8,*)E1, B1(1) , NUM(1)
       READ(8,*)E2, B1(2) , NUM(2)
       READ(8,*)E3, B1(3) , NUM(3)
       READ(8,*)E4, B1(4) , NUM(4)
C      WRITE(6,*)( B1(I) , NUM(I) , I = 1 , 4 )
       IF(TMC) 5001, 5001, 5000
 5000 DO 711 IM=1,NLAST
       SPEC(IM)=CO(IM)
  711 CONTINUE
```

```
C5000 READ(8,*)(SPEC(I), I = 1, NLAST)
C     WRITE(6,*)(SPEC(I), I = 1, NLAST)
      GO TO 5002
 5001 DO 722 IN=1,NLAST
      SPEC(IN)=CO(IN)
  722 CONTINUE
C5001 READ(8,*)(SPEC(I), I = 1,NLAST)
C     WRITE(6,*)(SPEC(I), I = 1,NLAST)
      READ(8,*)LIMC
      IF(LIMC.EQ.123456)WRITE(6,*)'CALIBRATION DATA ENTERED'
      IF(LIMC.NE.123456)WRITE(6,*)'CKECK CALIBRATION DATA'
 5002 IF (CHECK) 352, 352, 353
  352 K2 = 3
      GO TO  355
  353  K2 = 4
  355  DO 14  K3 = 1, K2
      J = K3
      NPTS  =  NUM(J)
      M =  B1(J)
      DO 3  K =  1, NPTS
      L =  M+ K - 1
      WRITE(6,*)L
      U(K)  =  ALOG ( SPEC (L) )
    3  W(K)  =  SPEC (L)
      DO 4  K =  1,  NPTS
      F(1,K)  =  1.0
      F(2,K )  =  K- 1
    4 F(3,K)  =  F(2,K) *F(2,K )
      L$ = 3
      DO 12 J = 1,L$
      DO 12 I = J,L$
      P(I,J) = 0.0
      DO 11 K = 1,NPTS
   11 P(I,J) = P(I,J) + W(K)*F(I,K)*F(J,K)
   12    P(J,I) = P(I,J)
      DO 13 I = 1,L$
      B(I) = 0.0
      DO 13 L = 1,NPTS
   13 B(I) = B(I) + W(L)*U(L)*F(I,L)
C     MATRIX INVERSION
      IF( L$ - 1 ) 307,307,49
  307 B(1) =  B(1)/ P(1,1)
      GO TO 306
   49 M1 = 2*L$ + 1
      DO 3012 J = 1 , M1
      DO 3011 K = 1 , L$
 3011 Q(K,J) = 0.
 3012 CONTINUE
      DO 23 I = 1,L$
      DO 20 J = 1,L$
   20 Q(I,J) = P(I,J)
   23 CONTINUE
      DO 3013 I = 1,L$
      L = L$ + I
 3013 Q(I,L) = 1.
      DO 59 I = 1,L$
   59 Q(I,M1) = B(I)
      DO 68 J = 1,L$
      IF ( L$ - J ) 3004,3004,60
   60 DO 61 I = J , L$
```

```
   61 T1(I) = ABS  ( Q(I,J) )
      M = J
      HOLE = T1(J)
      DO 63 I = J,L$
      IF ( HOLE - T1(I) ) 62,63,63
   62 HOLE = T1(I)
      M = I
   63 CONTINUE
      DO 64 K = J,M1
      BUMP1 = Q(J,K)
      Q(J,K) = Q(M,K)
   64 Q(M,K) = BUMP1
 3004 T1(J) = 1.0/Q(J,J)
      DO 65 K = J,M1
   65 Q(J,K)= T1(J)*Q(J,K)
      Q(J,J) = 1.
      IF (L$ - J ) 50,50,3005
 3005 M = J + 1
      DO 67 N = M , L$
      BOX = Q(N,J)
      DO 66 K = J,M1
   66 Q(N,K)= Q(N,K) - BOX*Q(J,K)
   67 Q(N,J) = 0.
   68 CONTINUE
   50 DO 3010 J = 1,L$
      L = L$ + 1 - J
      N2 = L$ - J
      DO 3007 K = 1,N2
      BOX = Q(K,L)
      DO 3006 M = L,M1
 3006 Q(K,M) = Q(K,M) - Q(L,M)*BOX
 3007 CONTINUE
      IF ( L-2 ) 51,51,3010
 3010 CONTINUE
   51 DO 53 I = 1,L$
   53 B(I) = Q(I,M1)
      DO 55  J= 1,  L$
      DO 54  I = J,L$
      L =  J+ L$
      P(I,J) = Q(I,L)
   54 P(J,I)  =  P(I,J )
   55 CONTINUE
  306 M = K3
      C(M)  =  -B(2) /(2.0*B(3) )
   14 CONTINUE
      C1 =  C(1) + B1(1)
      C2 =  C(2) + B1(2)
      C3 =  C(3) + B1(3)
      DENOM=C1*C1*(C2-C3)+C2*C2*(C3-C1)+C3*C3*(C1-C2)
      TOP1=E1*(C2-C3)+E2*(C3-C1)+E3*(C1-C2)
      TOP2=C1*C1*(E2-E3)+C2*C2*(E3-E1)+C3*C3*(E1-E2)
      X=TOP1/DENOM
      Y=TOP2/DENOM
      Z  = E3 - X*C3*C3 -Y*C3 + Y/2.0
      IF ( CHECK )  350, 350, 351
  351 C4 =  C(4) + B1(4)
      E5 = X*C4*C4 + Y*C4  +Z -Y/2.0
      WRITE(6,205)E5 , E4
  350 COEFF(1, LSPEC) = X
      COEFF(2, LSPEC) = Y
```

```
      COEFF(3, LSPEC) = Z
      AA= COEFF(1, LSPEC)
      BB=COEFF(2, LSPEC)
      CC=COEFF(3, LSPEC)
      WRITE(6,*)AA,BB,CC
C     WRITE(6,204) IANGL(LSPEC), (TITLE(I, LSPEC), I = 1, 5)
      WRITE(6,203)(COEFF(I, LSPEC), I = 1, 3)
      WRITE(6,203) E1 , E2 , E3
      WRITE(6,203)C1 , C2 , C3
      WRITE(6,207)
      IF(LSPEC - 10) 6000,6004,6000
 6004 WRITE(6,6003)
 6000 CONTINUE
      DO 6002 LSPEC = 1, NSPEC
C     WRITE(6,204)IANGL(LSPEC), (TITLE(I, LSPEC), I = 1, 5)
 6002 WRITE(6,203)(COEFF(I, LSPEC), I = 1, 3)
  203 FORMAT (3(3X, E13.6))
C 204 FORMAT (I5, 5A4)
  205 FORMAT(20H TEST PEAK, FITTED =,F10.4, 9H ACTUAL =,F10.4 )
  207 FORMAT (/)
 6003 FORMAT(1H1)
      RETURN
      END
C*********************************************************************
C*********************************************************************
C*********************************************************************
C*********************************************************************
C*********************************************************************
      SUBROUTINE SMOOTH (Y,NPTS)
      DIMENSION Y(4100)
 11   IMAX=NPTS-1
      YI= Y(1)
 21   DO 24 I=1,IMAX
      YNEW=(YI+2.*Y(I)+Y(I+1))/ 4.0
      YI=Y(I)
 24   Y(I)=YNEW
 25   Y(NPTS)=(YI+3.*Y(NPTS)) /4.0
      RETURN
      END
C*********************************************************************
C*********************************************************************
C*********************************************************************
C*********************************************************************
C*********************************************************************
      SUBROUTINE  LEVELS(LLEVEL,SPIN,NOL)
C     PRINT,'ONE'
      REAL LLEVEL(160)
      CHARACTER*8 SPIN(160)
      NOL=1
      LOOP
C     PRINT,'TWO'
C      READ(9,*)LLEVEL(NOL),SPIN(NOL)
        READ,LLEVEL(NOL),SPIN(NOL)
        ATEND,QUIT
        WRITE(6,*)NOL,LLEVEL(NOL),SPIN(NOL)
        NOL=NOL+1
      ENDLOOP
      NOL=NOL-1
C     PRINT,'THREE'
      RETURN
```

```
      END
C*********************************************************************
C*********************************************************************
C*********************************************************************
$ENTRY
```

REFERENCES

1. J. Chadwick, Nature, 129, 312 (1932)
2. J. Chadwick, Proc. Roz. Soc., A136, 692 (1936).
3. D. Iwanenko, Nature, 129, 798 (1932).
4. W.Z. Heisenberg, Physik, 77,1;ibid. 78, 156; ibid. 80, 587.
5. H.C. Urey, F.G. Brickwedde, and G.N. Murphy, Phys. Rev., 39, 164 (1932).
6. H.C. Urey, F.G. Brickwedde, and G.N. Murphy, Phys. Rev., 40, 1 (1932).
7. J.R. Oppenheimer, Phys. Rev., 35, 939 (1930).
8. P.A.M. Dirac, Proc. Roy. Soc. A133, 60 (1931).
9. C.D. Anderson, Phys. Rev., 48, 491 (1933).
10. E.Z. Fermi, Physik 88, 161 (1934).
11. J.D. Cockcroft, and Walton, E.T.S., Proc. Roy. Soc. A137, 229 (1932).
12. R.J. Van De Graaff, and Van Atta, Phys. Rev. 43, 149 (1933).
13. W.Z. Heisenberg, Phys. 77, 1 (1932).

14. M.A. Tuve, N. Hydenberg, and L.R. Hatstad, Phys. Rev. 43, 1055 (1933).

15. G. Breit, E.U. Condon and R.D. Present, Phys. Rev. 50, 825 (1936).

16. E. Wigner, Phys. Rev. 51, 106 (1937).

17. E. Wigner, Phys. Rev. 56, 519 (939).

18. R.K. Adair, Phys. Rev. 87, 1041 (1952).

19. N.M. Kroll and L.L. Foldy, Phys. Rev. 88, 1177 (1952).

20. W.A. Fowler, L.A. Delsasso, and C.C. Lauritsen, Phys. Rev. 49, 561 (1936).

21. H. Bethe, Rev. Mod. PHYS. 8, 82 (1937).

22. V.L. Fitch and J. Rainwater, Phys. Rev. 92, 789 (1953).

23. L.M. Cooper, and E.M. Hanely, Phys. Rev. 92, 801(1953).

24. A.B. Brown, C.Y. Chao, W.A. Fowler, and C.C.Lauretsen, Phys. Rev. 7, 88 (1949).

25. J.D. Anderson and C. Wong, Phys. Rev. Lett. 7, 250 (1961).

26. J.D. Anderson, C. Wong and J.W. McClure, Phys. Rev. 126, 2170 (1962).

27. J.D. Anderson and C. Wong, Phys. Rev. Lett. 8, 442 (1962).

28. J.D. Anderson, Isobaric Spin in Nuclear Physics, J.D. Fox and D. Robson, Editors, Academic Press, N.Y. 1966.

29. J.D. Fox, C.F. Moore, D. Robson, Phys. Rev. Lett. 12, 198 (1964).

30. D. Robson, Phys. Rev. 137, B535 (1965).

31. A.M. Lane, Phys. Rev. Lett. 8, 171 (1962).

32. P.Goldhammer and L.W. Seagondollar (Editors), Second Symposium on the Structure of Low-Medium Mass Nuclei, Ohio (1966).

33. S. Maripuu, Nucl. Phys. A123, 357 (1969).

34. S. Maripuu, Nucl. Phys. A153, 183 (1970).

35. S. Maripuu, Phys. Lett. 31B, 181 (1970).

36. I. Foder, I. Szentpetery and J. Szucs, Phys. Lett. 32B, 689 (1970).

37. I. Szentpetery and J. Szucs, Phys. Rev. Lett. 28, 387 (1972).

38. M. Sharader, H.V. Klapdor, G. Bergdolt and A.M. Bergdolt, Phys. Lett. 60B, 39 (1975).

39. J.F. Matega, G.F. Neal, J.D. Goss, P.R. Chagnor and C.P. Brown, Phys. Rev. C13, 118 (1976).

40. L. Satpathy and S.C. Gojrathy, Nucl. Phys. A110, 400 (1968).

41. J.M.G. Gomes, Phys. Rev. C6, 149 (1972).

42. A. Corello and V.A. Manferdi, Phys. Lett. 34B, 584 (1971).

43. K.W.C. Stewart, B. Castel and B.P. Singh, Phys. Rev. C4, 2131 (1971).

44. R.L. Auble, Nucle. Data Sheets 20, 327 (1977).

45. C.M. Sedrer, S.S. Shirley (Editors), Table of Isotopes. John Wiley and Sons, Inc. N.Y. (1978).

46. S.E. Arnell and P.O. Persson, Arkiv Fysik 26, 193 (1964).

47. P.O. Persson and S.E. Arnell, Arkiv Fysik 33, 371 (1966).

48. B. Rosner and C.H. Holbrow, Phys. Rev. 145, 1080 (1967).

49. H. Brandle, W.R. Wylie, F. Zamboni and W. Zich, Nucl. Phys A151, 211 (1970).

50. B.J. O'Brien and G.E. Coote, Nucl. Phys. A153, 593 (1970).

51. J.R. Leslie, W. McLatchie, C.F. Monahan and J.K. Thrashev, Nucl. Phys. A170, 115 (1971).

52. D.P. Lindstorm, H.W. Newson, E.G. Bilpuch and G.E. Mitchell, Nucl. Phys. A168, 37 (1971).

53. G. Hardie, T.H. Braid, L. Meyer-Schutzmeister, and J.W. Smith, Phys. Rev. C5, 1600 (1972).

54. S. El-Kateb and G.M. Griffiths, Nucl. Phys. A240, (1975) 120.

55. S. El-Kateb and G.M. Griffiths Z. Phys A30 (1981) 189.

56. Foder, J. Sziklai, B. Kardon, J. Rama Rao, K. Beckert, F. Hermann and H. Schobber, J. Phys 64, 1117 (1978).

57. C. Rangacharyalu, I.M. Szoghy, C. St. Pierr and K. Ramarataram, Phys Rev C19, 1762 (1979).

58. W.A. Watson III, E.G. Bilpuch and G.E. Mitchell, Phys. Rev. C24, 1992 (1982).

59. E. Arai, M. Futakutchi, H. Kamada, J. Komaki, T. Matsusaki, M. Ogawa and Y. Oguri, Nucl Phys A378 (1982) 259.

60. J.B. Marion and F.C. Young, Nuclear Reaction Analysis, Wiley and Sons (1968).

61. R.J. De Meijer, H.S. Blendl and R. Holub, Atomic Data Tables 13,1 (1974).

62. G.I. Harris, H.J. Hennecke and D.D. Watson, Phys Rev, B139,1113 (1965).

63. A.K. Hyder and D.D. Watson, Aerospace Research Laboratory Report, ARL67-0168 (1967).

64. G.U. Din, Nucl. Phys. A134, 655 (1969).

65. A. Adam, O. Bersillon and S. Joly, Phys. Rev. C14, 92 (1976).

66. M.M. Nagadi, "Search for the $g_{9/2}$ Analogue State in ^{59}Co Via The ^{58}Fe $(P,\gamma)^{59}Co$ Reaction", M.Sc. Thesis, University of Petroleum and Minerals, Dhahran, Saudi Arabia (1984).

67. A.J. Ferguson and A.R. Ruttedge, Atomic Energy Canada, Ltd. CRP-615, AECL-420, 1962 (unpublished).

68. P.B. Smith, Nuclear Reaction, edited by P.M. Endt and P.B. Smith (North Holland Publishing Company, Amsterdam, 1962), Vol. II.

69. P.B. Smith, Can. J. Phys. 42, 1101 (1964).

70. A.J. Ferguson, Angular Correlation Methods in Gamma-Ray Spectroscopy (North Holland Publishing Company, Amsterdam, 1965).

71. R.D. Gill, Gamma-Ray Angular Correlation (Academic Press, London, New York, San Francisco 1975).

72. D.H. Wilkinson, Nuclear Spectroscopy Part B, ed. F. Ajzenberg-Selove, Academic Press, N.Y. (1960).

73. S.A. Moskowski "Beta and Gamma-Ray Spectroscopy", ed., K. Siegbahn, North Holland Amsterdam (1955)